EFFECTS OF REVERBERATION TIME ON CLASSICAL SINGERS' PREFERENCES UPON MUSIC PRACTICE ROOMS

A Master's Thesis

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September 2015

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Graduate School of Economics and Social Sciences
of
İhsan Doğramacı Bilkent University

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In Partial Fulfillment of the Requirements for the Degree of
MASTER OF FINE ARTS

in

THE DEPARTMENT OF
INTERIOR ARCHITECTURE AND ENVIRONMENTAL DESIGN
İHSAN DOĞRAMACI BİLKENT UNIVERSITY
ANKARA

September, 2015

I certify that I have read this thesis and have found that it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Fine Arts in Interior Architecture and Environmental Design.

(Assoc. Prof. Semiha Yılmazer)
Supervisor

I certify that I have read this thesis and have found that it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Fine Arts in Interior Architecture and Environmental Design.

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ABSTRACT

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Özgün Sinal

MFA in Interior Architecture and Environmental Design

Supervisor: Assoc. Prof. Semiha Yılmazer

September 2015

The purpose of this study is to investigate the effect of reverberation time variances on classical singers' [*N*=30] preferences in individual music practice rooms. The method has combined objective measurements (RT) and perceptual responses of participants. The participant group [*N*=30] has consisted of five different backgrounds in vocal studies ; EME (early music education) students (*N*=6), skilled amateurs (*N*=5), undergraduate singing students (*N*=6), graduate singing students (*N*=5), and professionals (*N*=8). Classical singers has been asked to sing with as high and as low as they could with melisma singing style (in opera singing technique) in three different room settings which had following reverberation times; around 0.6 s, 0.8 s, and 1.0 s. These were the values, which acoustical standards for music schools recommended. The participants have also been asked to sing with three different singing volumes in each room setting. The findings have been analyzed statistically. According to the results, classical singers have preferred the room setting with 0.8 s reverberation time considering their overall experience in three different room settings. Classical singers' perceived singing effort has had a statistically significant relationship with preferred room setting. In addition, it has been found that there is a relationship between preference and background in vocal studies, which means that while experienced classical singers prefer dead conditions to live conditions, unexperienced classical singers prefer live conditions to dead conditions. It has also been found that, according to perceptual responses, experienced classical singers exert less singing effort while less experienced classical singers exert more singing effort in same room conditions.

Keywords: Reverberation Time, Music Practice Rooms, Perceived Singing Effort, Classical Singers.

ÖZET

KLASİK ŞANCILARIN MÜZİK ÇALIŞMA ODASI TERCİHLERİNE ÇINLAMA SÜRESİNİN ETKİSİ

Özgün Sinal

İç Mimarlık ve Çevre Tasarımı Yüksek Lisans Programı

Tez Yöneticisi: Doç. Dr. Semiha Yılmazer

Eylül, 2015

Bu çalışmanın amacı müzik çalışma odalarındaki çınlama süresi değişikliklerinin klasik şancıların tercihlerine etkisini incelemektir. Uygulanan yöntem, nesnel ölçümleri ve katılımcıların algısal cevaplarını bir araya getirmiştir. Katılımcı grubu [*N*=30], ses çalışmalarında beş farklı özgeçmişe sahip kişilerden; erken müzik eğitimi öğrencileri (*N*=6), yetenekli amatörler (*N*=5), üniversite öğrencileri (*N*=6), yüksek lisans öğrencileri (*N*=5) ve profesyonel opera sanatçılarından (*N*=8) oluşturulmuştur. Klasik şancılardan, çınlama süresi 0.6 s, 0.8 s ve 1.0 s dolaylarında olan oda ortamlarında tekli heceler halinde opera tekniğiyle çıkarabildikleri en bas ve tiz sesleri içerecek şekilde ses alıştırması yapmaları istenmiştir. Söz konusu çınlama süreleri ise müzik okulları için standartların önerdiği değerlerden oluşmaktadır. Katılımcılardan aynı zamanda bu alıştırmayı üç farklı şarkı söyleme şiddetinde tekrarlamaları istenmiştir. İstatistiksel veriler analiz edilmiştir. Buna göre, klasik şancılar, söz konusu üç farklı oda ortamındaki genel performanslarını değerlendirerek, çalışmak istedikleri oda ortamını çınlama süresini 0.8 s dolaylarında tercih etmiştir. Klasik şancıların algılanan ses eforları ve tercih ettikleri oda ortamı arasında istatistiksel olarak anlamlı bir ilişki bulunmuştur. Buna ek olarak, saptanmıştır ki oda ortamı tercihi ile ses çalışmalarındaki özgeçmiş arasında da ilişki vardır. Buna göre, tecrübeli klasik şancılar cansız koşulları canlı koşullara; tecrübesiz klasik şancılar ise canlı koşulları cansız koşullara tercih etmiştir. Ayrıca, bulunmuştur ki, algısal cevaplara göre tecrübeli klasik şancılar, aynı oda koşullarında tecrübesiz klasik şancılara göre daha az efor sarf etmiştir.

Anahtar Kelimeler: Çınlama Süresi, Müzik Çalışma Odaları, Algılanan Şarkı Söyleme Eeforu, Klasik Şancılar.

ACKNOWLEDGEMENTS

This thesis would not have been possible without splendid support and encouragement from several very important people.

Foremost, I would like to thank Assoc. Prof. Semiha Yılmazer for her guidance, moral and academic support, kindness, patient and sincere approach during my undergraduate and graduate studies. She has unveiled me a whole new world and encouraged me to have a better career. I would also like to thank Prof. Mehmet Çalışkan and Assoc. Prof. Çağrı İmamoğlu for all their advices.

I owe special thanks to the team members of Mezzo Stüdyo; Dr. Zühre Sü-Gül, Serkan Atamer, Zeynep Bora, and Işın Meriç-Nursal for all their support and their close friendship.

Sincere thanks to my good friends Didem Doğan, İlkin Alpay and Giray Bayer for their contributions to this work.

Lastly, I thank Gökçe Kutsal, not only for her several contributions to this work, but also for her patience, constant love, and invaluable friendship.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Architectural acoustics (room acoustics) aims to obtain a good sound quality within diverse spaces from concert halls to railway stations (Morfey, 2000). The first empirical study with modern scientific methods in architectural acoustics was carried out by Wallace Sabine. Sabine (1922), a physician and mathematician, was considered to be the first acoustician who investigated room acoustics in lecture halls, such as lecture rooms in the Fogg Museum and in Harvard University, in terms of room volume along with reverberation time and absorption. These experiences led him to develop a formula (Sabine's formula) for room absorption which is still used in the architectural acoustics field to calculate reverberation time according to the relationship between room volume and absorption on surface (Beranek, 2004). Later then, as another contribution to acoustical design field, Sabine integrated music and architectural acoustics with his investigation in Boston Symphony Hall. Therefore, detailed researches for concert halls have begun.

One of the greatest contributors to the study of concert hall architectural acoustics, Beranek, who celebrated his 100th birthday this year, reviewed several concert halls compiling information in his previous work. Beranek (2004), combined objective measurements and subjective evaluations in his compiled work. Since such spaces are designed for people, their subjective evaluations are required as well. Therefore, in order to determine which characteristics in acoustical design influence listeners, subjective evaluations act as confirmation towards acoustic in concert halls.

Objective measurements are used to determine overall acoustical quality in architectural attributes which are measured physically by reverberation time (RT), early decay time (EDT), clarity (C80), definition (D50), lateral fraction (LF), strength (G), and initial-time-delay gap (ITDG). On the other hand, subjective parameters used to evaluate overall acoustical quality from user perspective that are listed as subjective clarity, reverberance, envelopment, intimacy, loudness and warmth (Beranek, 2004). These two parameters should have high correlations in between to be considered as reliable (Sü, 2004).

Ternström (1991) recommended that sound should be studied by its production, propagation and perception as certain areas of architectural acoustics focus preferably on the perspectives of listeners and very few considers the musicians, particularly the singers (as cited in Hom, 2013, p. 8). It is crucial to analyze efficiency of singers' vocal sound along with their perceptions of the room while singing, and hearing their own voices (Hom, 2013).

Hom (2013) also argues that perceptions of listeners and performers are different. Hom's study on singers indicated that the rooms which performers prefer the most, affect listener perceptions negatively. In contrast, the rooms that listeners are expected to prefer, affect performer perceptions negatively. Since singers in music practice rooms practice their singing voices individually, their own perceptions are to be considered, unlike in concert hall evaluations.

Singing performers predominantly need to adjust their voices according to the different room environments from concert hall stages to small music practice rooms. Teachers and vocal coaches along with internet forums suggest ways and singing techniques on how to survive poor acoustics. Sataloff (2010) affirms the fact and suggests that instead of teaching the singers how to survive poor acoustics; acoustical experts should be consulted for design processes of music facilities. It is also suggested for singers to sing normally, as they get used to the rooms for practicing, so they can have better performances in every environment they perform. For this reason, the reserved rooms for singers should be acoustically suitable and efficiently designed in absorption. In this respect focusing on music practice rooms' acoustical conditions and the user' responses towards the rooms, singers spend most of their time, becomes a necessity.

1.1. Aim and Scope

This study is designed to see the effects of reverberation time on classical singers towards music practice rooms for individual usage purposes. The aim is to compare perceptual evaluations of performers by controlling the reverberation time. In this study, perceptual evaluations are acquired via questionnaires and in real environments in order to eliminate biased assessments towards simulated conditions. For this reason, singing practice rooms in Bilkent University Faculty of Music and Performing Arts have chosen for this case study. There are three different room settings arranged and designed to see the difference in participant responses. Arranging the acoustical conditions in room settings, potential problems emerging from the small volume and room geometry are eliminated where necessary. However, modal behavior of room settings is not analyzed in detail. Since the room modes subject is too complex by itself and requires too much effort to analyze, it is beyond the scope of this research. In other respects, the main acoustical parameter in this study is reverberation time. It is measured via ODEON simulation software which gives reliable results.

In this study, the main aim is to obtain reasonable findings related to singing effort. Singing effort is predominantly measured by exploring long time average spectra (LTAS) and the difference between sound levels can be analyzed. However, in this study, the participants' perceptions towards the singing effort they exerted are investigated based on the recommendations of professional opera singers who participated in the study.

1.2. Structure of the Thesis

The first of the five main chapters in this thesis, introduction presents the development of architectural acoustics on music spaces and gives brief information about the aim of the study along with the scope and structure of the present work.

In the second chapter, music practice rooms are described. Along with the requirements of these rooms and their users, potential acoustical problems are also given briefly. Then, empirical studies related to the present study are examined focusing on the effects of reverberation time on singers in unamplified music rooms (mainly concert halls). In this part, acoustical parameters of the rooms and perceptual measurement techniques are also described briefly.

In the third chapter, the design of the study formed according to the research questions is presented. It contains methodology, the most important part of the study, which systematically describes the approach to the study and preparations that are made to have contributive findings to the scientific research field. Measurement techniques and procedure along with the designed questionnaire are also described in this chapter.

In the fourth one, the results of reverberation time measured via computer simulation software and subjective evaluations of participants are given with relevant statistical analyses.

Lastly, in chapter five, results are interpreted and compared with the previous studies which are given in the second chapter. The further results are also reasoned and other possible consequences are evaluated. These are followed by the last chapter, conclusion, which was drawn according to the overall study.

CHAPTER 2

ACOUSTICS IN MUSIC PRACTICE ROOMS

Music practice rooms in music faculties are designed to provide practicing space for diverse user groups ranging from brass instrumentalists to classical singers for both ensemble studies, orchestral and individual practices (Osman, 2010). Apart from practicing musicians, these rooms are used for music teaching purposes as well. Music practice rooms mostly vary in size, volume, and geometry depending on the aim of usage.

Every musician, before each concert or recital, spends a considerable amount of time practicing his or her instruments. Especially music students spend up to 40 hours in a week in practice rooms (Lamberty, 1980). Considering the time spent, these rooms require a lot more attention to indoor sound quality as well as concert halls.

Music practice rooms also deserve suitable acoustics since musicians are learning and improving their skills by listening to their instruments. Particularly, as they are used for teaching purposes, students are to be informed about subtle concepts such as articulation, intonation, balance, dynamics and tone productions. In this case, poor acoustical conditions affect the development of basic musical skills of music students negatively (Osman, 2010). More importantly, such concerns are among the most probable reasons of having poor performances in concerts and recitals.

For hierarchical reasons in an architectural manner, music practice rooms are designed to be small areas. Small music rooms are known to have problematic acoustical properties if they are not treated carefully. At the beginning, noise control and isolation have been the main concerns in their design (Osman, 2010). However, carelessly projected absorption amount may lead to unforeseeable and unintended consequences. Recent studies on music practice rooms have focused on issues such as hearing problems emerging from loud instruments, noise exposure, and vocal strain that musicians face due to poor acoustical conditions.

2.1. Music Practice Room Requirements

As stated in the previous paragraph, musicians playing loud instruments, such as brass instruments, suffer from hearing problems while singers suffer from vocal strain because of practicing with high-intensity. It is obvious that their requirements in a music practice room are different.

Regardless of their musical degree, singers have a common point in *covering* their voices. This term is often used when referring to protecting voice against vocal damage (Miller, 1996). Many singers taking singing lessons are taught strictly about their voice usage. There are several techniques taught in singing education, especially classical singing, that focus primarily on vocal comfort in order to eliminate the vocal strain that results in shorter careers. Particularly while producing higher and lower notes, singers often have difficulties and if the voice is forced, *vocal folds* (sometimes misleadingly called *vocal cords*) may permanently be damaged. Vocal folds of singers are actually their instruments. For this reason, singers always carry the burden of covering their voices.

Protect themselves from upper respiratory infections which may be damaging to their throats are also priorities for singers. In such cases, the process of education is given a break until full recovery from the illness is achieved or the scheduled concerts/recitals are cancelled.

Instrumentalists and singers have the mutual aim of learning and improving their playing and singing techniques in music practice rooms. Learned technique is expected to be maintained and improved throughout the education process. If the wrong technique is learned, it is difficult to reform.

Along with the common points, musical instruments and singing voice have different sound characteristics and frequency ranges. Figure 1 shows the highest and lowest notes of instrument groups and singing voice. Besides, produced sound levels of musical instruments are different. For this reason, either music practice rooms are to be designed to cover all requirements, or cover each instrument groups separately such as wind, brass, bow instruments, and voice.

Simply put, the singing voice has seven major voice categories that are for the most part acknowledged across all the major voice classification systems (Stark, 2003). Female voices are typically divided into three main groups: 1) soprano, 2) mezzo-soprano, and 3) contralto while male voices are divided into four main groups: 1) countertenor, 2) tenor, 3) baritone, and 4) bass. The following table, Table 1, shows the general vocal ranges related with each singing voice type using scientific pitch notation. One should know that some singers could sing higher or lower than their specified singing voice types (Miller, 1996).

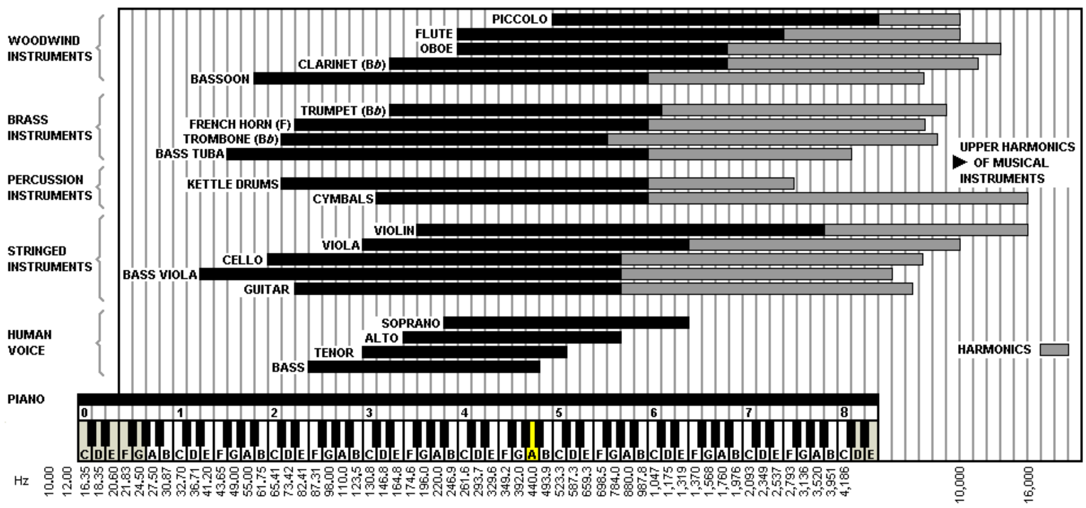


Figure 1. Ranges of singing voice and musical instrument frequencies

Table 1. General vocal ranges in scientific notation and related frequency ranges

Singing Voice Type	Note range	Frequency Range (Hz)
Bass	E2 – E4	82.41 – 329.63
Baritone	G2 – A4	98.00 – 440.00
Tenor	C3 – C5	130.81 – 523.25
Countertenor	E3 – E5	164.81 – 659.25
Contralto	F3 – F5	174.61 – 698.46
Mezzo-soprano	A3 – A5	220.00 – 880.00
Soprano	C4 – C6	261.00 – 1046.50

Music practice room should fulfil the requirements of musicians by providing the best-fit acoustical parameters that allow them excellent auditory perceptions. Two of the most important requirements for acoustical comfort are a suitable reverberation time (RT) according to the aim of the room, and elimination of problems emerging from the small room size such as strong resonances and flutter echoes.

2.1.1. Reverberation Time (RT)

In a general scientific description, reverberation time (RT) is defined as the time, required for the average sound energy density to decay by 60 dB from an equilibrium level after stopping a sound source (Sü, 2004). It is controlled by the total absorption and volume of the room and it is dependent on frequency.

It can be calculated using Sabine's formula as presented below:

$$\mathbf{T_{60} = 0,161 \times V / A_t}$$

where,

T_{60} = reverberation time, or the time takes for a sound to decay by 60 dB (s)

V = volume of the room (m^3)

A_t = total area of absorption in the room (sabins) (Egan, 2007)

There are two additional formulas for calculation of reverberation time which are proposed by Norris-Eyring and Millington & Sette (Egan, 2007). They are also valid and currently in use in the field of architectural acoustics.

According to Australian/ New Zealand Standard on Acoustics-Recommended Design Sound Levels and Reverberation Times for Building Interiors, AS/ NZS 2107:2000 (2000), The American National Standards Institute's (ANSI) Design Requirements and Guidelines for Schools standard, S12.60 (2002, 2010), Department for Education and Skills' Building Bulletin 93, on Acoustical Design of Schools, BB93 (2003, 2015), optimum reverberation times should be around 0.6 s - 1.0 s band. Related RT values are presented in Table 2.

Since reverberation is a volume dependent acoustical parameter, as the room volume increases, so does RT. Figure 2 is illustrating the optimum RT by volumetric variance.

Table 2. Optimum RT for music practice rooms

Standards	Volume (m3)	RT (s)
AS/ NZS 2107:2000 (2000)	Not Specified	0.5 – 0.7
ANSI S12.60 (2002)	< 283	< 0.6
ANSI S12.60 (2010)	< 283	< 0.6
BB93 (2003)	(See Figure 2)	< 0.8
BB93 (2015)	≤ 30	≤ 0.61 - ≤ 0.82
	> 30	≤ 0.81 - ≤ 1.02

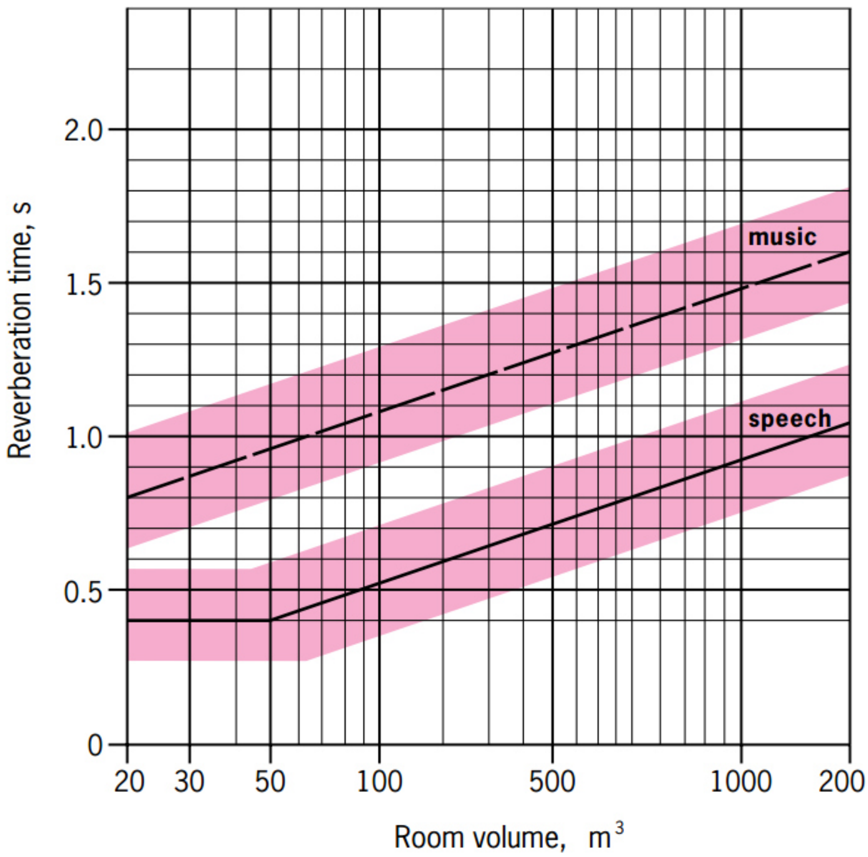


Figure 2. Optimum mid-frequency RT for speech and music as a function of room volume

[1] Suggested RT value for newly built music practice rooms
[2] Suggested RT values for refurbished music practice rooms

2.1.2. Limitations in Small Volumes

As stated, reverberation time is a primary acoustical parameter in room acoustics. However, for small room acoustics, it may not be adequate. Even if the correct reverberation time according to main aim of the room is provided, undesirable reflections (flutter echoes) and room resonances pose perceptional problems such as loudness at particular lower frequencies (BB93, 2003). Accordingly, along with reverberation time, there are two other factors are to be investigated designing small practice rooms.

Flutter echo can be described as a rapid series of echoes (especially in small rooms) arising from reflection between two parallel surfaces. In order to eliminate them, untreated surfaces should not face each other (Osman, 2010). In addition, flutter echoes can also be minimized by adding diffusive surfaces where necessary such as quadratic residue diffusers (QRD) as proposed by Schroeder (1975). Diffusion (or scattering such as bookshelves) also contributes to the balance of the sound in a music practice room along with increasing the communications between teachers and students. Despite eliminating flutter echoes, standing waves that can cause acoustical problems may not be prevented.

Standing waves, which emerge from room modes, can be described as a low frequency resonance which takes place between two parallel surfaces. In other words, where the distance between two parallel walls interferes, a standing wave arises and the balance of the sound will be affected (BB93, 2003). For instance, singing in bathroom the one may realize that some certain notes make the room resonate by enhancing the sound level and often a boomy sound is perceived. For this reason, in rectangular small rooms, room modes should be taken into consideration.

The very first empirical study concerning room modes was published by Mors & Bolt (1944). The researchers mainly focused on axial modes since they are the strongest modes. After that, Bolt (1946) developed a pair of formulas without defining any criteria for how room modes should be. Eventually, the subject of determining particular room ratios was discussed by other researchers. The following room ratios by worldwide respected acousticians using the positioning of axial, tangential, and oblique modes are accepted worldwide: 1:1.14:1.39 and 1:1.6:2.33 by Sepmeyer (1965), and 1:1.4:1.9 by Louden (1971). Along with these, Louden determined 125 more ratios. Yet, there were no certain criteria for the best room concerning well-distributed room modes. Instead, Schroeder's widely used formula is used in order to determine the lowest frequency.

The Schroeder Frequency, also known as cut-off frequency, is commonly used to define the crossover between the low frequency regions, dominated by particular room modes (Schroeder, 1962). The related frequency can be calculated with the following formula:

$$\mathbf{F_S = 2000 \times (T/V)^{0.5}}$$

where,

F_S = Schroeder Frequency (Hz)

T = Expected reverberation time (s)

V = Volume of the room (m^3) (Everest & Pohlmann, 2009)

In other words, Schroeder frequency indicates how reliable the results of reverberation time calculations are. Below that limit frequency, modes can be expected to dominate the room acoustic conditions. Therefore, a deeper investigation to the modal behavior of the room setting may be required.

2.2. Effects of Reverberation Time on Singers' Performance

This section reviews empirical research literature related to the effects of reverberation time on singers' performance. Although the focus of this thesis is on the effect of reverberation time along with perceptions of singers in individual practice rooms, studies investigated aforementioned subjects in smaller music rooms, such as practice rooms, are rare. Yet, eight other investigations (Marshall & Meyer, 1985; Ternström, 1989; Guyette, 1996; Noson et al., 2000, 2002; Skirlis et al., 2005; Stetson & Braasch, 2009; Hom, 2013) focusing on the effects of acoustics in concert halls on singers have useful findings to examine for this study.

Investigations on concert halls have been studied concerning both objective measures and subjective evaluations of listeners since Sabine's days. Further investigations have focused mainly on performers in terms of the effects of reverberation time and perceived acoustical quality.

Moorcroft and Kenny (2013) investigated classical singers' and listeners' tonal quality perceptions before and after predesigned warm-up exercises. Twelve professional female classical singers were asked to learn and sing an eight bar solo, designed for this study, before and after 25 minutes of warm-up exercises and rate their own performances. Six experienced listeners were asked to evaluate each vocal sample, recorded in a recording studio rather than an anechoic chamber, in terms of tonal quality. Dramatically, all singers perceived statistically significant differences in tonal quality along with psycho-physiological factors, proprioceptive feedback, and technical command (brilliance, energized alertness, resonant voice sensations, and vocal connection throughout the body) as listeners observed differences only in vibrato quality.

Blankenship, Fitzgerald, and Lane (1955) presented a comparison of acoustical measurements and subjective evaluations of the users in music practice rooms, rehearsal rooms and auditoriums in The University of Texas in order to evaluate them in terms of their adequacy for music performance, and to integrate the contribution of the musician along with the architectural acoustician on music room designs. In the study, researchers determined three identical practice rooms around 12 m^3 volumes. Instrumentalists along with classical singers (n=20) were asked to perform in the room as it is. Then, rooms were treated with absorbent wall panels in several ways. Participants were asked to evaluate room settings in terms of tonal quality, dynamic range and reverberation after each session was completed. The results showed that the room with around 0.5 s reverberation time (RT) was desired among room settings with 0.4 s and 0.8 s RT. Researchers also asked the same participants to evaluate two teaching rooms which had different volumes, but around 70 m^3. Reverberation time in related rooms was fixed to 0.6 s by using draperies. All participants indicated that these two teaching studios were far better than practice rooms. Besides, the larger teaching studio was found to be better.

Guyette (1996) investigated the effects of acoustical conditions on five professional opera singers (3 soprano, 2 tenor) towards ten different concert hall conditions focusing on physical and psychological singer adjustment along with perceptions on their own performances. Participants were to sing their own choice of operatic arias in an anechoic chamber. Participants were asked to evaluate their perception of the room and their own performance in each simulated acoustic condition according to sound recordings. Listeners (n=3) were also asked to evaluate each of these recordings. Then, listeners' perceptions and singer perceptions were compared. Unfortunately, listeners were able to evaluate only two of the recordings of singers. For this reason, the results were statistically insignificant. However, according to singer perceptions, the anechoic room conditions were found to be artificial.

Stetson & Braasch (2009) performed a similar study which investigated singers' preferences towards acoustical characteristics of five different concert halls focusing on singers' own auditory perceptions. In this study, ten professional classical singers (5 mezzo-soprano, 3 soprano, 1 tenor; ages 21-70) were asked to sing in and evaluate related concert halls according to their own performance by using a head and torso simulator capturing singers' mouth and ears which enables a real-time auralization. Objective measurements were provided using impulse response technique and transferred to the simulator. According to results, regardless of the genre and singers' positions in the stage there was a statistically strong connection between increasing preference and increasing reverberation time.

Skirlis, Cabrera and Connolly (2005) investigated vocal effort variations in small and large halls. In the study, eight professional opera singers were asked to imagine a small hall and a large hall for different two sets and were asked to sing one song excerpt, which was the final 16 bars of a traditional Italian song, in an anechoic chamber. According to results, participants produced greater sound levels for large hall renditions compared to small hall.

Marshall and Meyer (1985) investigated the directivity and auditory impressions of professional singers. The study consisted of two parts. At first stage, the directivity of three professional singers (1 soprano, 1 alto, 1 baritone) was measured in anechoic conditions. Participants were asked to sing three vowels in two singing volumes, full voice (fortissimo) and half voice (pianissimo). According to their results, the floor reflection was found to be particularly important as the area covered 2 to 5 meters in front of singers. In the second part of the study, auditory impressions of singers were explored with experiments in hemi-anechoic conditions. The results indicated that singers' auditory impression was influenced by reverberation rather than early reflections.

Noson, Sakai, Sato and Ando (2000) were interested in what acoustical changes might be crucial for singers. An on-site preliminary study was done in a church with choir singers (bass to soprano). Singers were asked to perform two short passages with slow and fast tempos respectively. First results showed that, for solo performance with a slow tempo, with added reflections from speakers (10 ms to 40 ms delay) nearly had no influence on singers' preference. On the other hand, with a fast tempo, solo singers were affected by the presence of simulated reflection and they preferred a delay range between 20 ms and 30 ms. Researchers carried this study to an anechoic environment. This time, a similar study was applied to four singers. According to the results, tempo caused no chances and the singers preferred shorter delay times between 13-21 ms.

Noson et al. (2002), investigated the similar study with different singing styles consisting of melisma singing (with and without lyrics). This time, six singers were asked to sing in semi-anechoic conditions. According to the results, the participants' preferences differed between singing with lyrics and without lyrics.

Ternström (1989) studied the effects of acoustics in three different rooms consisting of a church hall with 3.90 s reverberation time (RT), a choir rehearsal room with 0.85 s RT and a small absorbent room with 0.34 s RT. The researcher also studied the effects of singing effort. Three different choirs consisting of a boy's, a youth and an adult choir participated in this study. As the youth and adult choir were asked to perform mixed-voice versions of two different songs, the boy's choir was asked to produce only the melody in unison for each room with three different singing volumes (pianissimo to fortissimo). According to long-time average spectra (LTAS) measures, statistically significant differences were found between two songs and singing volumes. According to their overall results, the choirs' exerted singing effort increased in the absorbent condition which means as the reverberance decreased, exerted singing effort increased considerably.

Hom (2013) performed a similar study to explore the effects of acoustical and perceptual measures in two different rooms consisting of a choir rehearsal room and a performance hall. Eleven university student choristers (4 soprano, 3 alto, 2 tenor, 2 bass) and thirty-three listeners participated in Hom's study. Chorister participants were asked to learn and sing a song composed for SATB voices in each room and each song was recorded in-situ. Reverberation time calculated for the rooms was around 2.00 s in rehearsal room (791 m^3) and around 1.45 s in performance hall (1900 m^3). According to their results, within the same room, listeners' and performers' perceptions are different. As listeners preferred the rehearsal room, performers preferred the performance hall considering its acoustical characteristics. Besides, sound pressure level differences of singers in different rooms were statistically significant. As for the results of the survey applied to singers indicated that singers’ individual perceived singing effort was slightly more in performance hall which had a slightly less RT than rehearsal room.

Considering the researches mentioned in this section, the majority of studies focused on concert halls in order to determine the effects of reverberation time on classical singers and their preferences. In addition, evaluations of the participants in aforementioned studies were taken in anechoic conditions instead of real environments. Only one study, performed by Blankenship et al. (1955), studied the related subject in both real environment and in music practice rooms.

Only three studies, Ternström (1989), Skirlis et al., (2005) and Hom (2013), examined singing effort in different acoustical conditions. Only one study, Hom (2013), examined perceived singing effort on singers (choristers). However, no study to date, explored perceived singing effort of individual classical singers in music practice rooms along with how perceived singing effort influences their preferences towards different acoustical conditions.

The aim of this study is to focus on how the perceived singing effort influences the RT preference of classical singers upon individual singing practice rooms. Furthermore, this study investigates the optimum RT in practice rooms along with the differences of subjective and perceptual responses of classical singers concerning their background in vocal studies.

CHAPTER 3

METHOD

3.1. Design of the Study

The purpose of this study is to explore the effects of reverberation time (RT) on classical singers' preferences. For this purpose, three room settings with different reverberation times were prepared in two identical practice rooms. In this context, music practice rooms reserved for classical singers in Bilkent University Faculty of Art Music and Performing Arts, Department of Music were chosen for the case study.

Objective measurements such as reverberation times were measured using computer simulation software while subjective evaluations were obtained through a questionnaire. The group [*N*=30] consisted of participants from five different backgrounds in vocal studies ; EME (early music education) students (*N*=6), skilled amateurs (*N*=5), undergraduate singing students (*N*=6), graduate singing students (*N*=5), and professionals (*N*=8). The data were analyzed statistically.

3.1.1. Research Questions

The following research questions directed the study:

1) What is the most preferable RT in a music practice room for classical singers?

2) Is there any relationship between perceived exerted singing effort and preference of RT in a practice room; classical singers' perceived exerted singing effort and their background in vocal studies in music; classical singers' background in vocal studies and preference of RT in a practice room?

3.1.2. Hypotheses

The hypothesis drawn was as follows:

1) The most preferable RT in a music practice room for classical singers is around 0.6 second.

2) There is a negative correlation between perceived exerted singing effort and preference of RT in a practice room; classical singers' perceived exerted singing effort and their background in vocal studies in music; classical singers' background in vocal studies and preference of RT in a practice room.

3.2. Methodology

The study was divided into two parts: acoustical parameter measurements using simulation software and subjective evaluations through a questionnaire and respondent comments.

3.2.1. Objective Measurements

Two identical singing practice rooms were determined. Their dimensions were 7.3m*5.4m*3.2m (L*W*H) and their volumes were 128 m^3. Furthermore, their dimensional ratios were 1: 1.68: 2.28. Nearest known ratio, to indicate that the room modes are well distributed, is Sepmeyer's (1965), 1: 1.60: 2.33. There were absorbent panels with dimensions of 1.4m*0.60m*0.03m (L*W*H) on the walls. Additionally there was a single window of (L*W) 0.9 m*1.2 m, a wooden door of (L*W) 2.1 m*0.9 m, and some furniture consisting of a cabinet, table & chairs, and a piano along with a piano stool. The only difference between these two identical rooms was floor materials. The first one had a heavy carpet floor material while the other one had parquet flooring.

According to a rough calculations using Sabine's formula (Sabine,1922), the room with carpet floor had around 0.6 s reverberation time as it was, and the other room (with parquet flooring) had around 0.8 s, in middle frequencies (500 Hz and 1000 Hz). After calculating that the present room settings were around 0.6 s and 0.8 s, an additional room setting was created which had 1.0 s RT by changing the distribution and the number of absorbers on the walls of the room with 0.8 s RT. From sidewalls, 7 absorbent panels have been homogeneously removed and set to be staggered. Rear wall was left to be absorbent. This way the amount of absorption was reduced as flutter echoes between parallel walls were prevented. Therefore, as design guidelines' and acoustical standards' suggested (see Chapter 2) RT values in between 0.6 s and 1.0 s band were defined to have a comparative case.

Eventually, three different room settings were arranged, as seen in Figure 3, Figure 4, and Figure 5. Their reverberation times were set to be different, from dead condition to live condition respectively, and expected to be around 0.6 s, 0,8 and 1.0 s as a result of computer simulation results. Room setting 1 (RS1), the dead setting, had carpet floor finishing with 23 absorbent panels on the walls. Room setting 2 (RS2), the midway setting, had parquet flooring with the same number and distribution of absorbent panels. As for room setting 3 (RS3), it had parquet floor with 16 absorbent panels on the walls.

As room modes are quite important for the design of the acoustical environment of small music rooms in rectangular shapes, the room settings were evaluated for their geometry using an online room mode calculator before the study. There were no axial modes multiple within 5%, and no tangential or oblique modes overlapped in one particular frequency. As explained in Chapter 2, since there is no certain criteria for the most well distributed room modes, one should know that the room modes were not taken into consideration in this study. Instead, Schroeder's widely used cut-off formula was used to determine the lowest frequency (for more details, see Chapter 2, p. 12).

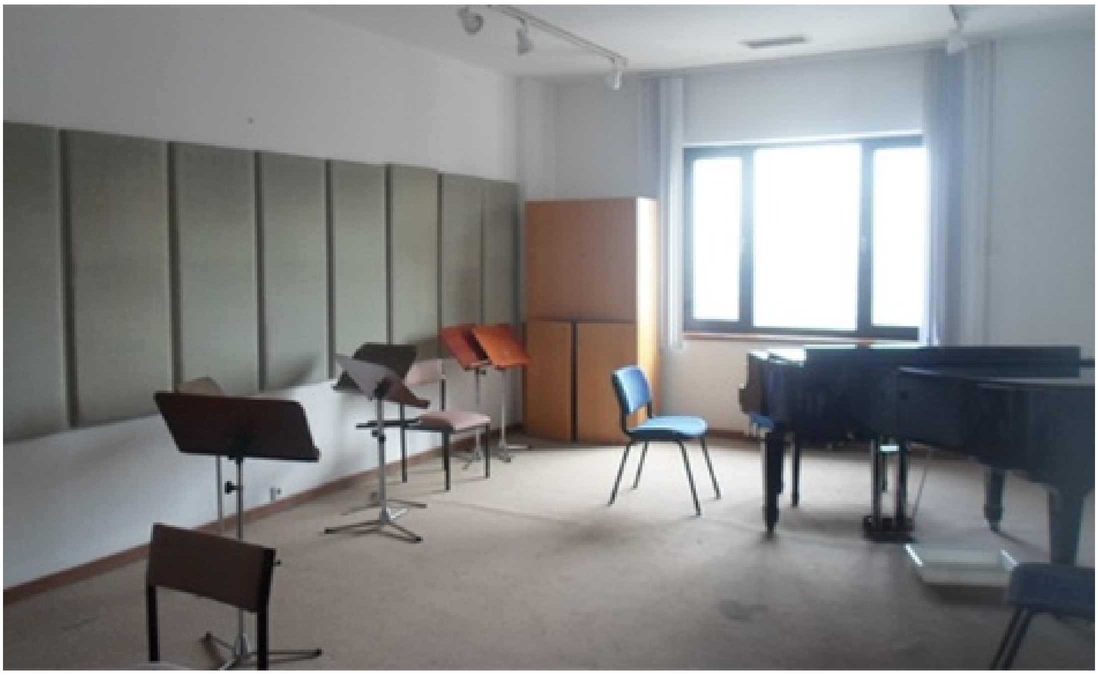


Figure 3. Photograph of room setting 1

Figure 4. Photograph of room setting 2

Figure 5. Photograph of room setting 3

Each room setting was modelled using Timbre SketchUp 2014 and carried out to ODEON Room Acoustics Software, version 8.5. ODEON models of room settings are presented in Figure 6, Figure 7, and Figure 8.

Figure 6. ODEON model of room setting 1

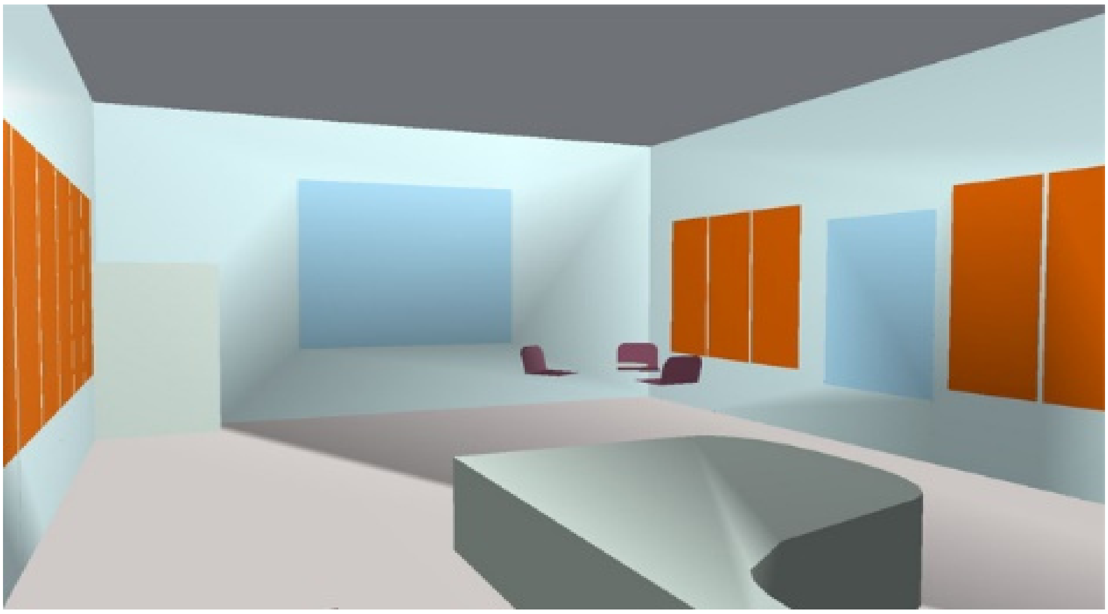


Figure 7. ODEON model of room setting 2

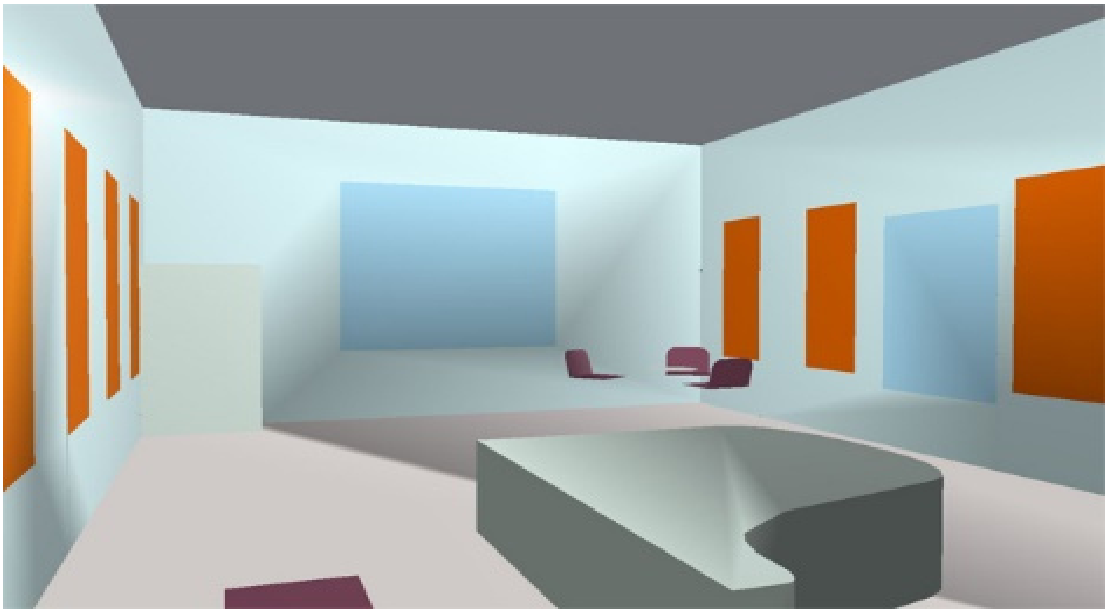


Figure 8. ODEON model of room setting 3

ODEON is a room acoustics software creating and simulating real-life environment (ex. concert & conference halls, offices, listening rooms and so on) and making prophetic predictions accordingly. Due to its large finishing material input, acoustical parameters can be measured and are used in acoustical design field for many years (Brüel & Kjaer, 2010).

However, although there was no statistical difference found between results of real-size measurements and computer simulation, in low frequencies (below 250 Hz) the simulated values may not follow the trend of the measured values (Christensen, Koutsouris & Rindel, 2013). The low frequency material data has a higher degree of error due to modal effects that occur during measurement of the absorption data (Brüel & Kjaer, 2011). For this reason, a real-size measurement via internal e-sweep signals of DIRAC 3.0 Room Acoustics Software Type 7841 was processed in one of the room settings to see the validity of the results in low frequency region.

DIRAC 3.0 Room Acoustics Software measures acoustical parameters by using a computer with soundcard and microphone and calculates the frequency spectrum along with many acoustical parameters with impulse response technique.

Therefore, for real size measurements, the instruments used were DIRAC 3.0 Room Acoustics Software Type 7841 along with B&K Omnipower Sound Source Type 4296, B&K Power Amplifier Type 2716, and B&K Sound Level Meter Type 2230.

3.2.2. Subjective Measurements

Classical singers (*N*=30) were asked to perform a vocal warm-up exercise ,singing as high and as low as they could in each room setting in melisma singing style (singing of a single syllable of text while moving between several different notes in succession) with opera technique. A warm-up exercise, which is predominantly used by classical singers, consisting of conjoined five notes, changes according to the reference tone, was redesigned by one of the graduate singing students from Bilkent University, Faculty of Music. Therefore, a new warm-up exercise became more complex with conjoined nine notes. The new warm-up exercise was also maintained as moderate in each reference sound. The participants were also asked to sing with different singing volumes from pianissimo (softest) to fortissimo (loudest). Reference tones were presented by the piano shortly before producing each vocal sound. Each session per singer was completed in around 5 minutes so that they could test their perceptions in the room settings better.

To limit the study, the position and facing direction of participants were fixed. Sound source, shown in Figure 9, in room setting represents the positions of the participants. The position in ODEON model were arranged to be approximately 1.5 m from the ground and placed in the middle.

In order to eliminate order and learning effects, the participants were asked to perform in random rooms every other day. Therefore, preconceived opinions towards room settings were prevented considerably.

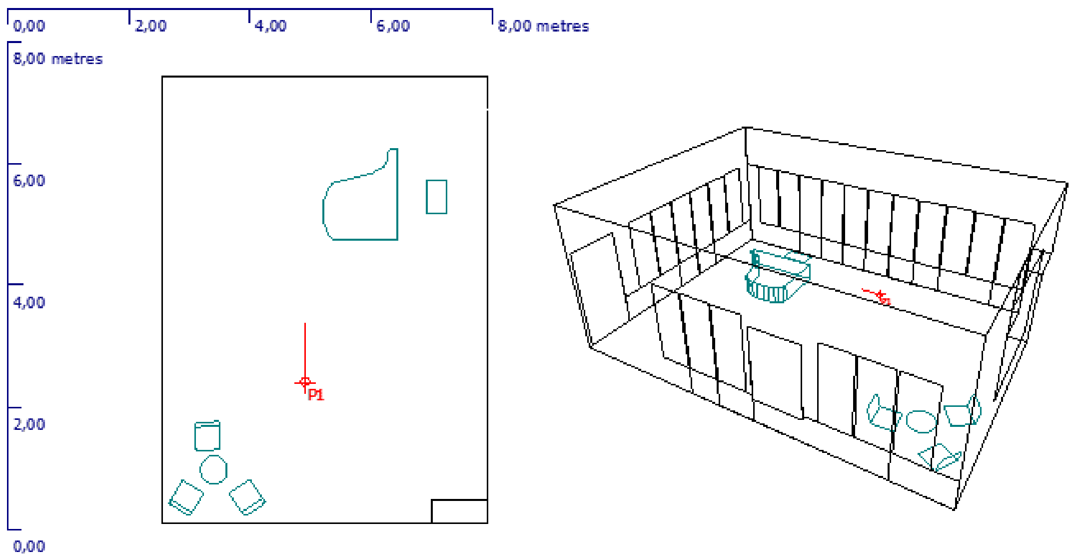


Figure 9. Sound source position in each room setting

Participants reported that they had been classically singing for at least 3 years and had no hearing problems. Additionally, all classical singers signed an informed consent form prior to data collection for the sake of procedure.

Before beginning each session, participants were asked to fill the first two parts of the relevant questionnaire form to collect data about their background in vocal studies, age, and gender along with their practicing routine, concert schedule in a year, and any previous problems they had in music practice rooms. The questionnaire consisted of four parts. After each singing session, participants were asked to fill the remaining two parts. In the last two parts, questions were about their experiences in practice rooms and mainly about their perceived exerted singing effort, satisfaction levels, and preferences towards rooms considering their overall experience. Subjective evaluations were also collected through open-ended comments about their experiences at the end.

The questionnaire was designed using tick boxes to make it more user-friendly along with a Likert scale. It was also prepared in English. Since the participants had a proficiency in English, a Turkish version of the questionnaire was not needed.

CHAPTER 4

RESULTS

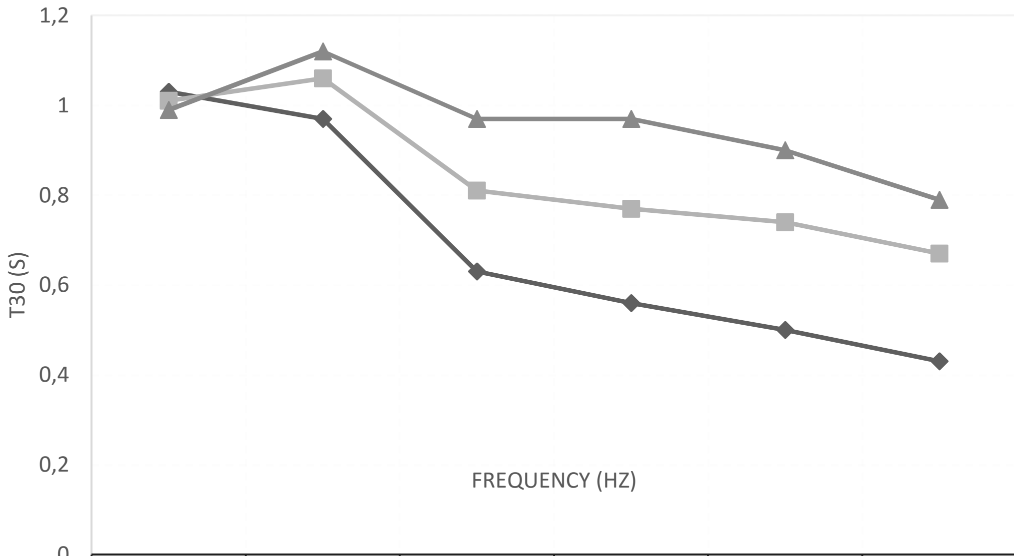
This chapter presents results based on the research questions posed for this study. Reported results include objective measurements, and subjective evaluations along with statistical analyses.

4.1. Objective Measurements

4.1.1. Reverberation Time (RT)

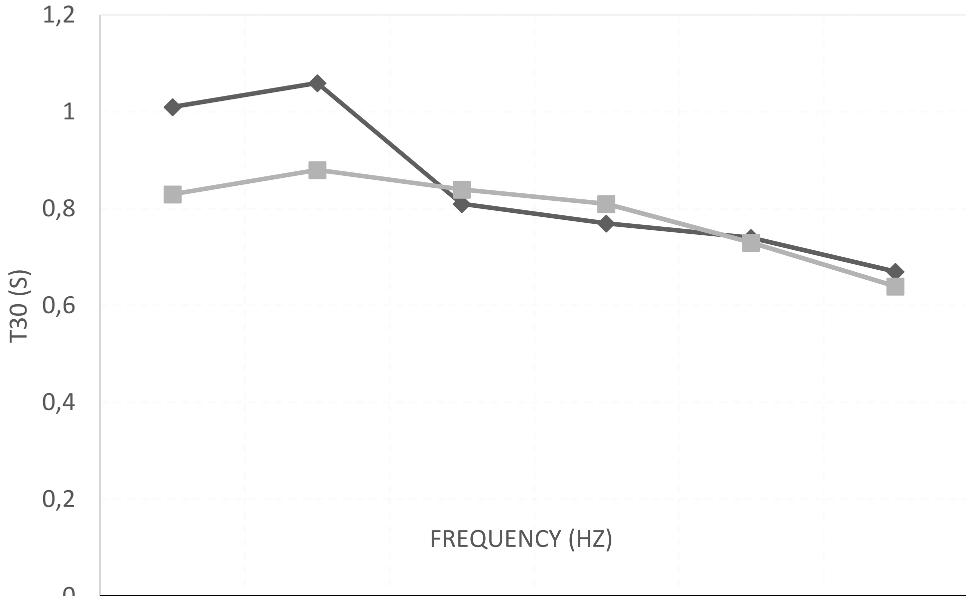
Reverberation times (T_{30}) for each room setting measured using ODEON Simulation Software and they are presented in Figure 10. For spaces with such small volumes and basic room geometry, T_{30} indicates better results than T_{20}. In order to see the difference between the results of T_{20} and T_{30}, see Appendix A.

In order to see the difference of reverberation times (T_{30}) and test the validity of simulation results, particularly in low frequencies, room setting 2 (RS2) was measured using DIRAC 3.0 Room Acoustic Software as well.



	125	250	500	1000	2000	4000
RS1	1,03	0,97	0,63	0,56	0,5	0,43
RS2	1,01	1,06	0,81	0,77	0,74	0,67
RS3	0,99	1,12	0,97	0,97	0,9	0,79

Figure 10. Measured RT values via ODEON for each room setting



	125	250	500	1000	2000	4000
ODEON	1,01	1,06	0,81	0,77	0,74	0,67
DIRAC	0,83	0,88	0,84	0,81	0,73	0,64

Figure 11. Measured RT values for RS2 via ODEON and DIRAC

Measured RT values via ODEON and DIRAC are shown in Figure 11. As seen, the real-size measurement results are lower than simulation results in low frequencies (125 Hz – 250 Hz). Nonetheless, measured reverberation times in mid and high frequencies Hz are very close (500 Hz – 4000 Hz). For extensive real-size measurement results see Appendix A.

Surface materials in room settings and their absorptive areas (m^2) are shown in Figure 12, which presents the difference in terms of measured amount of absorption in each room setting.

Results of RT measurements showed that Sabine calculations, which were calculated while designing the methodology, were as expected. At this point, in order to see if there is a statistically significant difference between RT mean values of three different room settings, One Way ANOVA Test was run. Results indicated a significant difference among RT data of each room setting at the $p<.05$ [$F(2, 12) = 4.29$, $p=0.049$]. However, this result was only valid for the frequency range between 250Hz to 2000Hz in 1/3 octave band.

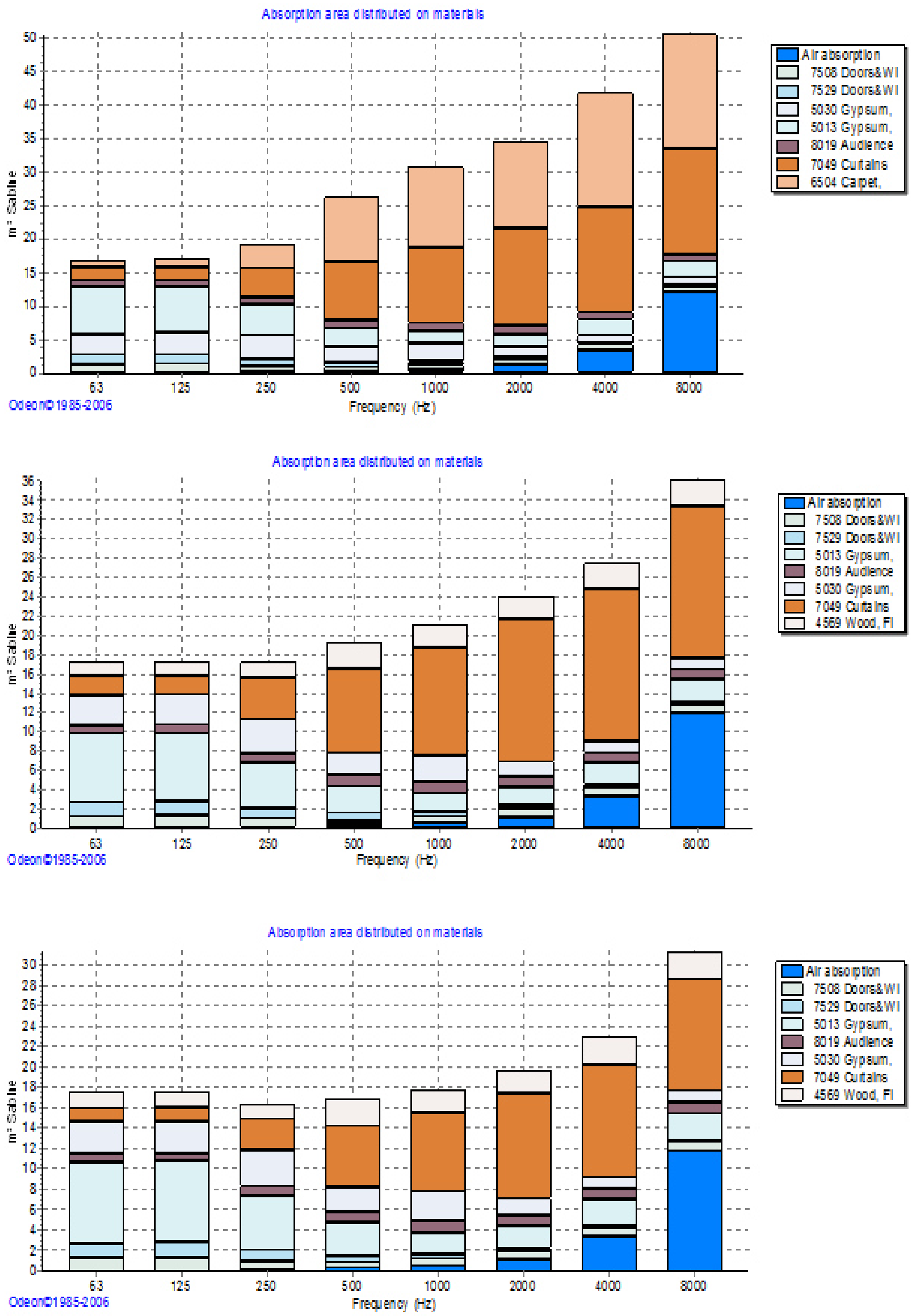


Figure 12. Absorption area distributed on materials for RS1, RS2 and RS3 consecutively

4.1.2. Schroeder Frequency

Schroeder frequency is known to be the minimum frequency limit (see Chapter 2) and as the study field was small rooms, Schroeder frequency was emphasized. Therefore, the most reliable RT results for room settings could be acquired. Relevant Schroeder frequencies were shown in the Table 3. According to Schroeder Frequency results, to make estimations for below frequencies specified, a deeper investigation to the modal behavior of the room setting was needed.

Table 3. Calculated Schroeder frequency values for each room setting

Room Settings	App. RT values (s)	Schroeder frequency (Hz)
1	0.6 s	136
2	0.8 s	158
3	1.0 s	176

Therefore, the frequency range was determined to be between 250 Hz and 2000 Hz in the 1/3 octave band considering both the Schroeder frequency as the lowest point for each room (136 Hz for RS1, 158 Hz for RS2, and 176 Hz for RS3) and the high-pitched sound frequency of a soprano voice (1046.5 Hz).

4.2. Subjective Evaluations

Data taken from 30 classical singers according to their experience in different room settings were analyzed to provide a reasonable conclusion to study. The following title gives the basic information about the participants.

4.2.1. Questionnaire results

4.2.1.1. Sample group

Classical singers had six different voice characteristics consisting of bass (*N*=1), baritone (*N*=4), tenor (*N*=5), countertenor (*N*=2) contralto (*N*=2), mezzo-soprano (*N*=4), and soprano (*N*=12) as presented in Table 4. Gender distribution of the participants was as follows: 18 female, 12 male. The age range was between 15 to 30 years (M = 23.2, SD = 5.11). Participants' backgrounds in vocal studies were distributed from the very first beginning of music education process to complete professional shown in Table 5.

Table 4. Vocal types of participants

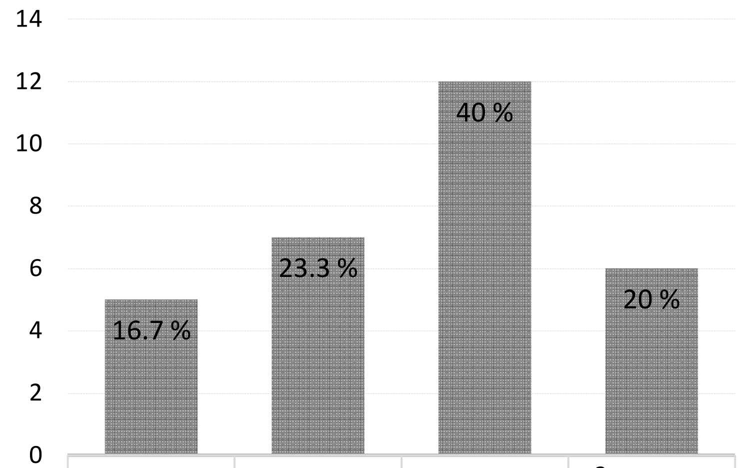
Vocal types of participants	**Frequency**	**Percent (%)**
Bass	1	3,3
Baritone	4	13,3
Tenor	5	16,7
Countertenor	2	6,7
Contralto	2	6,7
Mezzo-soprano	4	13,3
Soprano	12	40,0
Total	30	100,0

Table 5. Participants' background in vocal studies

Background in vocal studies	Frequency	Percent (%)
Early music education students	6	20,0
Skilled amateurs	5	16,7
Undergraduate students	7	23,3
Graduate students	4	13,3
Professionals	8	26,7
Total	30	100,0

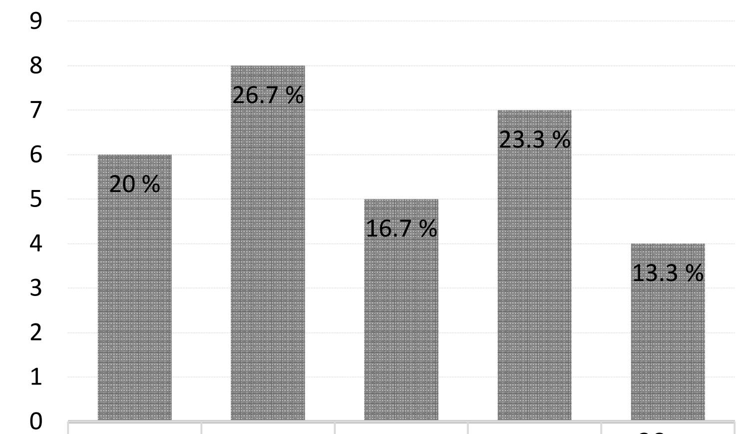
As for the yearly concert/recital schedule of the participants and the time they usually spend in a regular weekly routine in the music practice rooms, the data is given in Figure 13 and Figure 14.

All the participants mentioned that they had no permanent hearing loss to date. All participants grasped the basic concept of reverberation time and they agreed with the statement that reverberation time was affecting their performances as well. The majority (*n*=20, 66.6 %) have suffered from vocal strain during a daily practice at some point.



	0 - 2 recitals	3 - 5 recitals	6 - 8 recitals	9 or more recitals
Number of concerts/ recitals performed in a year	5	7	12	6

Figure 13. Number of concerts/ recitals participants usually perform in a year



	0 - 4 hours	5 - 9 hours	10 - 14 hours	15 - 20 hours	20 or more hours
Time usually spent in a week in music practice rooms	6	8	5	7	4

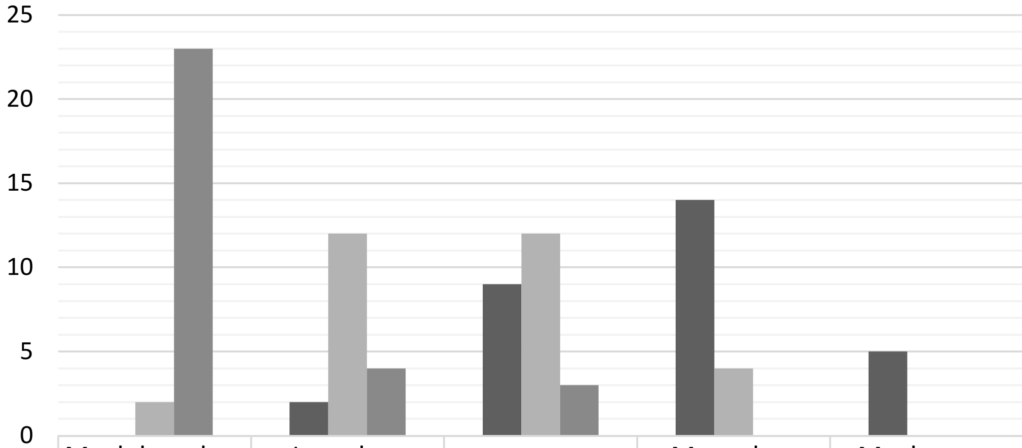
Figure 14. Time usually spent in a week in music practice rooms

4.2.1.2. Room perceptions

The following questions were designed and addressed to the participants to find out how they perceive 1) *their signing effort*, 2) *the low and high-pitched notes*, and 3) *three major singing volumes* in each room settings. Since dependent variables in this part of the questionnaire were designed to be ordinal, Kruskal-Wallis (K-W) H test was run to see if there is any statistically significant difference between them in each room setting. At this point, one should know that the Kruskal-Wallis H test does not give results about which specific groups of the independent variable are statistically significantly different from each other. For this reason, if there was a significant difference found with K-W, Tukey post-hoc test was applied to see which of these groups differ from each other.

Question - How did you perceive your *exerted singing effort* in this room setting? This question was asked to participants in each room setting to analyze how the perceived singing effort is influenced by RT. The question offered the following responses along a Likert-type scale: 1) *much more than normal*, 2) *more than normal* 3) *normal*, 4) *less than normal*, 5) *much less than normal*.

Even though the term *perceived singing effort* may not have been easy to explain, all participants were already familiar with the term. In Figure 15 and Table 6, the frequencies along with their means and standard deviations are shown. Kruskal-Wallis H test results showed that there was a statistically significant difference between perceived exerted singing efforts in room settings, $\chi 2(2) = 59.22$, $p = 0.0001$, with a mean rank perceived singing effort level of 21.47 for Room Setting 1, 43.30 for Room Settings 2 and 71.73 for Room Setting 3. A Tukey post-hoc test revealed that the perceived singing effort was statistically significantly different in each room setting at $p < .01$ (p_1, p_2, p_3=0.0001).



	Much less than normal	Less than normal	Normal	More than normal	Much more than normal
RS1	0	2	9	14	5
RS2	2	12	12	4	0
RS3	23	4	3	0	0

Figure 15. Perceived singing effort in each room setting

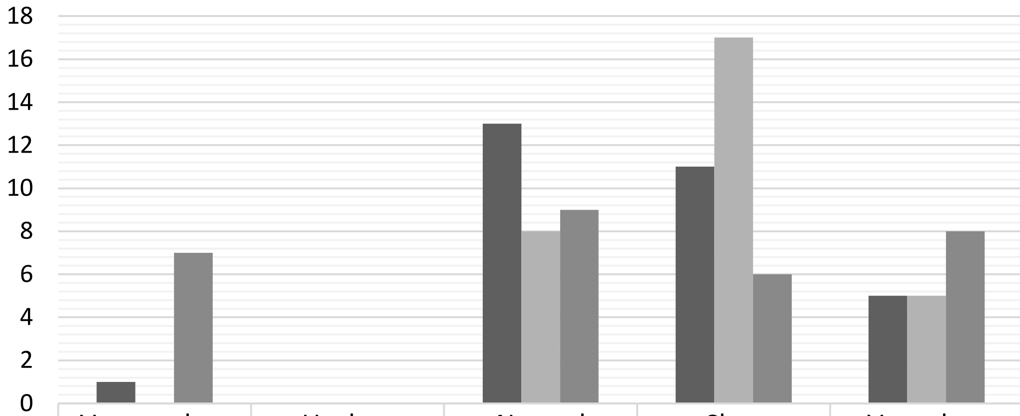
Table 6. Mean and standart deviation for perceived singing effort

Room Settings	Mean	Standard Deviation
1	2.27	,828
2	3.40	,814
3	4.67	,661

Question - How did you perceive the *low notes* in this room setting? The purpose of this question was to acquire insight on participants' perception about the sound quality in the room settings. If there were any statistically significant differences between room settings related to perceived low notes, then the actual questions posed for this study would have biased answers from the participants.

The question offered the following responses along a Likert-type scale: 1) *very unclear,* 2) *unclear,* 3) *neutral,* 4) *clear*, 5) *very clear*.

In Figure 16 and Table 7, the frequencies along with their means and standard deviations are shown. According to K-W H test results, there was not a statistically significant difference between perceived low notes in each room setting, $\chi2(2) = 2.734$, $p = 0.255$, with a mean rank perceived singing effort level of 44.27 for Room Setting 1, 51.30 for Room Settings 2 and 40.93 for Room Setting 3.



	Very unclear	Unclear	Neutral	Clear	Very clear
RS1	1	0	13	11	5
RS2	0	0	8	17	5
RS3	7	0	9	6	8

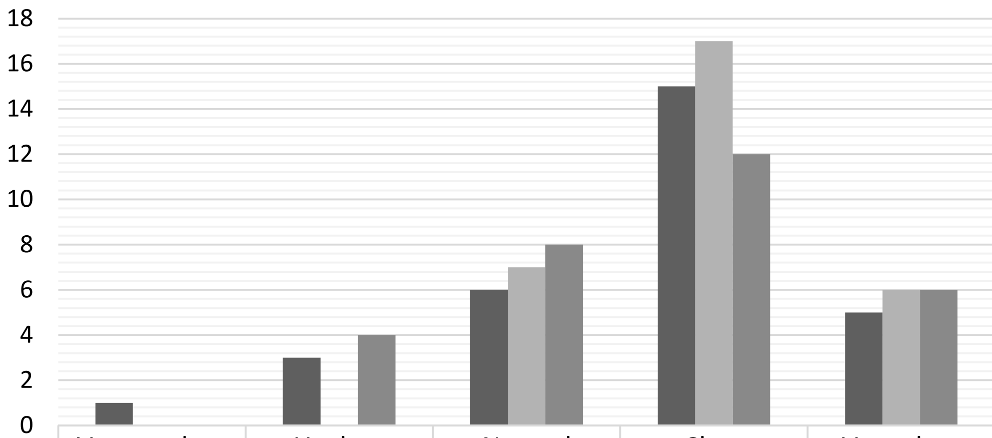
Figure 16. Perception of low notes in each room setting

Table 7. Mean and standart deviation for perception of low notes

Room Settings	**Mean**	**Standard Deviation**
1	3.67	,802
2	3.90	,662
3	3.50	1,137

Question - How did you perceive the *high notes* in this room setting? The question offered the following responses along a Likert-type scale: 1) *very unclear,* 2) *unclear,* 3) *neutral* , 4) *clear*, 5) *very clear*.

Similar to perceived low notes, K-W test results showed no difference between perceived high notes between each room setting, $\chi2(2) = 1.584$, $p = 0.453$, with a mean rank perceived singing effort level of 43.75 for Room Setting 1, 50.02 for Room Settings 2, and 42.73 for Room Setting 3. In Figure 17, frequencies, and in Table 8, mean values of high note ratings and related standard deviations are presented.



	Very unclear	Unclear	Neutral	Clear	Very clear
RS1	1	3	6	15	5
RS2	0	0	7	17	6
RS3	0	4	8	12	6

Figure 17. Perception of high notes in each room setting

Table 8. Mean and standart deviation for perception of high notes

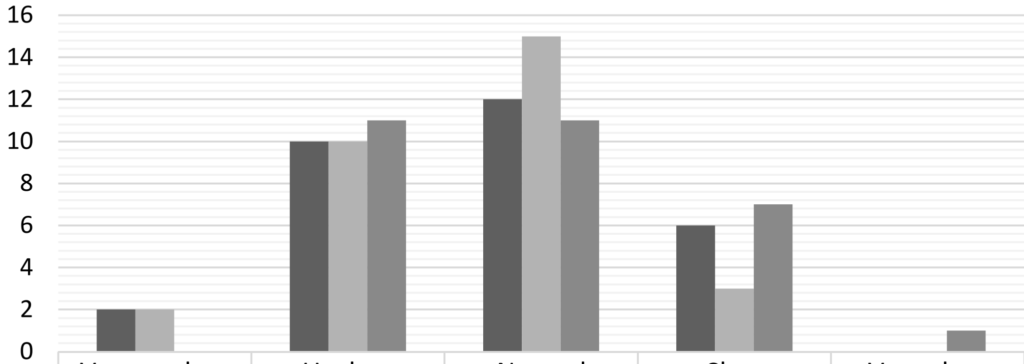
Room Settings	Mean	Standard Deviation
1	3.67	,994
2	3.97	,669
3	3.67	,959

Question - How did you perceive 1) *pianissimo-paced parts,* 2) *mezzo-forte-paced parts* 3) *fortissimo-paced parts* in this room setting? The purposes of the following three questions were to acquire participants' perception about how they hear their own voices with different singing volumes in each room setting. The question offered the following responses along a Likert-type scale: 1) *very unclear,* 2) *unclear,* 3) *neutral,* 4) *clear*, 5) *very clear*.

In Figure 18, Figure 19, and Figure 20, frequency of participants' responses is presented for each room setting consecutively. For mean values and standard deviations for perception of different singing volumes towards each room setting, see Table 9.

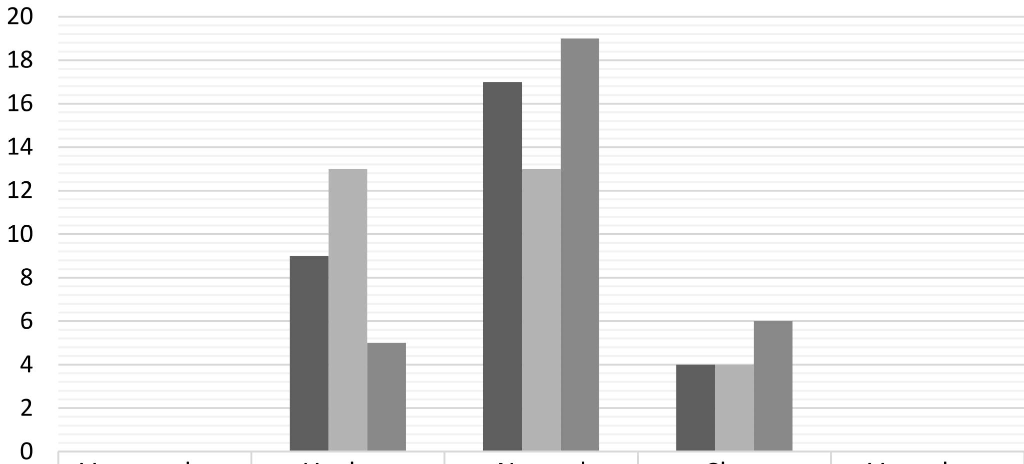
There was no statistically significant difference between perceived pianissimo-paced parts of the warm-up exercise in each room setting, $\chi 2(2)=3.60$, $p=0.165$, with a mean rank perceived singing effort level of 40.20 for Room Setting 1, 44.027 for Room Settings 2, and 52.03 for Room Setting 3.

There was no statistically significant difference between perceived mezzo forte-paced parts of the warm-up exercise in each room setting, χ2(2)=1.45, p=0.485, with a mean rank perceived singing effort level of 47.18 for Room Setting 1, 48.08 for Room Settings 2, and 41.23 for Room Setting 3.



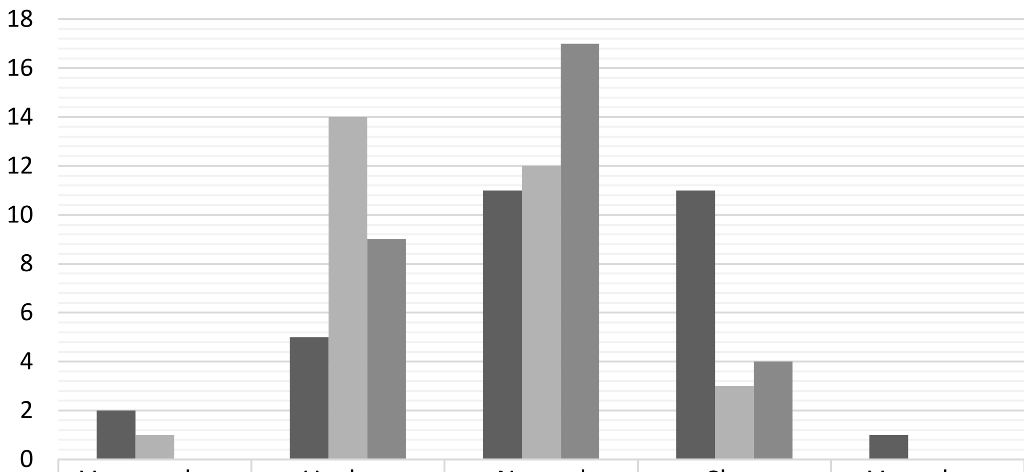
	Very unclear	Unclear	Neutral	Clear	Very clear
RS1	2	10	12	6	0
RS2	2	10	15	3	0
RS3	0	11	11	7	1

Figure 18. Perception of pianissimo-paced parts in each room setting



	Very unclear	Unclear	Neutral	Clear	Very clear
RS1	0	9	17	4	0
RS2	0	13	13	4	0
RS3	0	5	19	6	0

Figure 19. Perception of mezzo-forte-paced parts in each room setting



	Very unclear	Unclear	Neutral	Clear	Very clear
RS1	2	5	11	11	1
RS2	1	14	12	3	0
RS3	0	9	17	4	0

Figure 20. Perception of fortissimo-paced parts in each room setting

Table 9. Mean and standart deviation for perception of each singing volumes

Room Settings		Mean	Standard Deviation
1	Pianissimo	2,73	,868
	Mezzo-forte	2,63	,765
	Fortissimo	2,93	,868
2	Pianissimo	2,83	,648
	Mezzo-forte	2,70	,702
	Fortissimo	3,03	,615
3	Pianissimo	3,13	,973
	Mezzo-forte	2,57	,728
	Fortissimo	2,83	,648

There was no statistically significant difference between perceived fortissimo-paced parts of the warm-up exercise in each room setting, $\chi2(2)=1.74$, p=0.418, with a mean rank perceived singing effort level of 45.00 for Room Setting 1, 49.80 for Room Settings 2, and 41.70 for Room Setting 3.

4.2.1.3. Preference of room settings

Participants responded to the following question; considering your overall experience, which room setting would you prefer for practicing? The question offered the following responses: 1) Room setting 1, 2) Room setting 2, 3) Room setting 3.

According to the results, seen in Figure 21, the most preferred room setting to practice is RS2, which had 0.8 s RT. Most of the participants also (*n*=23) indicated why they preferred practicing in the room setting they have chosen. A selection of their answers is presented in Table 10.

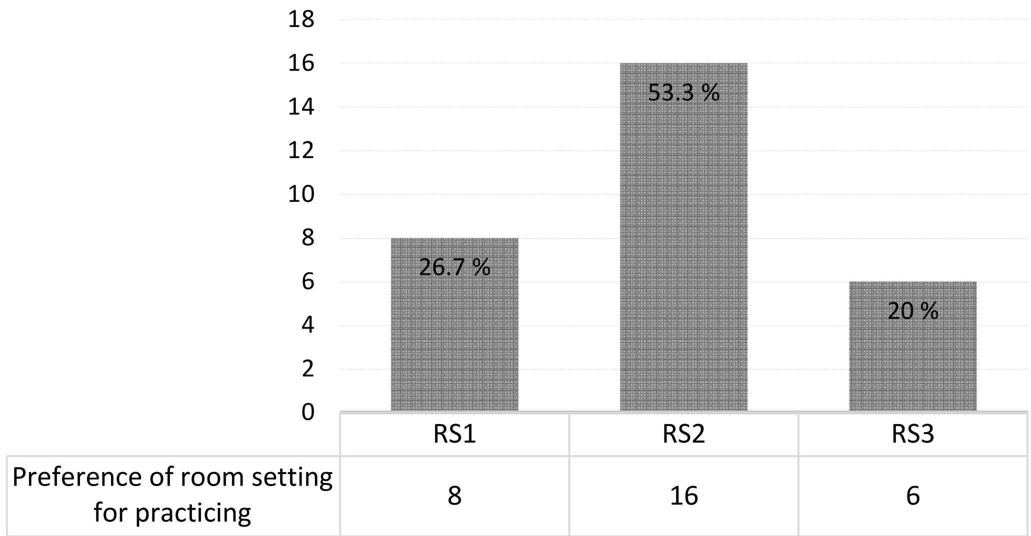


Figure 21. Preference of room setting for practicing

Table 10. A selection of the participant responses indicating why did they prefer to practice in the preferred room setting

Preference	Why ?
1	- I always prefer to practice in absorbent conditions to keep my vocal strength. - I can realize my mistakes in this room setting. That is why I prefer to practice in this room setting.
2	- Our instructors encourage us to sing louder. I can hear myself in this room setting and exert some effort. - This room setting is neither unresponsive nor too reverberant - My vocal coach suggests me to practice in a room like this.
3	- I can hear myself properly with less effort. - Acoustics, in this setting, is better than the other ones.

4.2.2. Statistical Analyses

Relationship between perceived exerted singing effort of the classical singers and their RT preferences was questioned. If any, how the perceived exerted singing effort influenced the RT preference among 0.6 s, 0.8 s and 1.0 s could be revealed. A Rank-Biserial correlation was run to explore the relationship between room settings and perceived singing effort. There was a moderate, negative correlation between them, which was significant at the $p < 0.01$ [$r_{rb}(30) = -.614$, $p = .0001$]. Related correlation table is shown in Appendix D.

Relationship between perceived exerted singing effort of the classical singers in each room setting and their background in vocal studies was questioned as well. A Spearman's rank-order correlation was run to examine the related relationship. According to this analysis, there was no correlation between perceived exerted singing effort of the participants and their background in vocal studies at the $p < 0.01$ and $p < 0.05$ [$r_s(30) = .392$, $p = -.162$]. Related correlation table is shown in Appendix D. Nevertheless, five variables of background in vocal studies were recoded as two variables as unexperienced classical singers (early music education students, skilled amateurs, undergraduate students) and experienced classical singers (graduate students, professionals) a different result was found. In order to achieve further results, a chi-square test of independence indicated that perceived singing effort of the participants was associated with education level of participants in music, χ (2, N = 30) = ,520, $p < .001$, Cramér's V = .017.

Relationship between participants' background in vocal studies and their RT preferences was also questioned. If any, how background in vocal studies influence the RT preference among 0.6 s, 0.8 s and 1.0 s could be revealed. Once more, Rank-Biserial correlation was run to determine the relationship between aforementioned variables. There was a negative correlation found between them, which was statistically significant at the $p < 0.01$ [$r_{rb}(30) = -.594$, $p = .001$]. Related correlation table is also shown in Appendix D.

CHAPTER 5

DISCUSSION

In this chapter, the choice of methods in this study is discussed including possible influence of methodological biases, errors on data validity. Furthermore, the central results and potential implications are discussed. This chapter also contains general limitations and weaknesses of the study. Overall, the results and the methods compared with the literature, presented in Chapter 2, and final arguments form the basis for the conclusions.

5.1. Relationship between perceived singing effort on RT preference

In this study, the relationship between perceived singing effort and preference of reverberation time (RT) in a music practice room has been questioned. As indicated in Chapter 2, no study to date tested the influence of perceived singing effort on classical singers' preferences of RT. At this point, the influence of background in vocal studies on perceived singing effort and preference of RT was also questioned.

A change in acoustical condition regarding reverberation time could affect classical singers in unamplified conditions. Classical singers might change and compensate their vocal technique according to the room absorption as Skirlis et al. Stated (2005). The researchers found that classical singers produced greater sound levels in large hall renditions (higher RT) compared to smaller halls (lower RT). Controlling RT and changing the room size, Hom (2013) found that choristers exerted more singing effort in large performance halls (smaller RT) and smaller rehearsal rooms (higher RT). It means that regardless of room volume, there is a strong and direct connection between RT and singing effort. Another study testing choristers' singing effort with changing RT was performed by Ternström (1989) and in absorbent conditions exerted singing effort increased. Therefore, a negative relationship expected to be found between perceived singing effort and preference of RT. In this study, it was revealed with the statistical results that singing effort had an influence on RT preference of classical singers. Such that, as perceived singing effort decreases, preference of singers tend towards higher reverberation times among 0.6 s, 0.8 s, and 1.0 s.

Similarly, background in vocal studies had an influence on perceived singing effort. As the background in vocal studies increased from early music education level to professional level, perceived singing effort decreased considerably. It may have stemmed from the experience in music practice rooms and the singing techniques developed over several years. It seems that, background in vocal studies was also correlated with RT preferences.

The results also indicated that, professional classical singers preferred to practice in dead conditions over live conditions while amateur classical singers preferred live conditions to dead conditions. Overall, the most preferred room condition was the midway of live and dead conditions with 0.8 s reverberation time. However, although, a moderate correlation was found between perceived singing effort and preference of RT, unexpectedly the most preferable practice room setting had 0.8 s RT instead of 1.0 s. In this regard, Beranek (2004) stated that reverberation provides musicians with “fullness-of-tone” in rooms for music. Most of the studies within literature addressed that reverberation time has a strong influence on classical singers’ preference. Furthermore, according to Stetson & Braasch (2009), there is a strong connection between increasing preference and increasing reverberation time. As this study shows, however, too much reverberation in music practice rooms is not preferred. It appears that in individual music practice rooms, classical singers do not prefer to practice in neither dead nor live conditions. Classical singers’ comments towards their preferences also show that, although they are satisfied with live conditions since they can hear their own voices properly, they would like to practice in optimum conditions to both hear their voices clearly and exert some effort to prepare better for stage performances. Such results are found to be consistent with the study performed by Blankenship et al. (1955) that musician participants including singers preferred around 0.5 s RT over a 0.8 s.

5.2. Methods on Classical Singers

Regarding the vocal types and the classical singers' vocal ranges, the method generally used to measure the sound energy in order to determine the actual frequency range to consider analyzing reverberation time (RT) results is *spectrum analyzer*. In this study, the vocal ranges of the classical singers were actual or there were minor differences up to a semitone. In other words, the vocal types specified in Table 1 (Chapter 2) show consistency with the vocal range of the classical singers. For this reason, spectrum analyzer was not used in this study.

According to Egan (2007), differences in sound levels are interpreted as 1 dB = "imperceptible", (b) 3 dB = "just barely noticeable", (c) 6 dB = "clearly noticeable" and (d) 10 dB = "about twice (or half) as loud" (as cited in Hom, 2013). Ternström (1989, 1991) and Hom (2013) used long time average spectra (LTAS) to obtain sound pressure level differences between room spectral energy. Hom also obtained perceived singing effort data of choristers through a questionnaire. The results of SPL of sound levels and perceived singing effort showed consistency. As for this study, perceived singing effort data were obtained as similarly as in Hom's study. The reason was that, classical singers' singing effort may differ according to their moods and the time spent for warm-up exercises before practices.

Graduate students (n=2) from Bilkent University and professional opera singers, graduated from Bilkent University (n=2) were consulted before the study in order to discuss possible limitations and imperfections of the preliminary research method of the present study. Judging by their experiences, they agreed upon the idea that a classical singer may sing with a greater sound pressure level one day, and may sing with lower sound pressure level the other day. Therefore, a change in SPL of a classical singer may be influenced by their moods along with their warm-up routines. Regarding this influence, it was thought that evaluation of perceived singing effort obtained through questionnaire would give reasonable results.

Another subject under method discussion was the importance of warm-up exercises before performance. According to Moorcroft & Kenny's study (2013), classical singers perceived the difference between their performances before and after a warm-up exercise for 25 minutes. Since in this study classical singers were asked to prefer a room setting among different RT values considering their overall experience took about 5 minutes for each session, being warmed-up before the preference test would influence their preferences.

One of the factors, which also might influence the responses of classical singers, was the song choice for such studies. Beranek (2004) indicated that preferred values of acoustical parameters depend on repertoire in concert halls. Beranek also specified different values for symphonic music, chamber music, and opera. Skirlis et al. (2005) indicated that preferred values might chance according to the genre. Guyette (1996), let performers to choose their own songs to perform. Even if there was no statistically drawn conclusion, performing different songs might result in different perceptions and preferences towards the music rooms.

Noson et al. (2000) asked performers to sing two short passages of the same song for a study. After two years, same researchers (2002) tried a different singing style melisma singing with and without lyrics as research method. For such studies, melisma singing was found to be a reasonable method to take song choice as a control factor. For this reason, in this study, melisma singing with one particular syllable word was determined and applied to participants. To control genre, classical singers were asked to sing with melisma singing style as long as it was sung using opéra technique.

One last strength under discussion is on distinctions between the applied methods; using an anechoic chamber and a real environment in research field, concerning perceptions of musicians was that, anechoic conditions had been found to be unrealistic and artificial. Even if they provide variety of options and are more efficient, which is accepted worldwide and widely used for such studies, perceptions of classical singers might be influenced while both experiencing the environment and evaluating the recordings in digital platforms. In the studies, performed by Guyette (1996) and Gunnlaugsdóttir (2008), participant musicians stated that the surroundings in the anechoic chambers were unnatural to them. The graduate students and the professional opera singers, who were unofficially interviewed before the study, indicated that they would prefer to be examined in their own practicing environments rather than artificial environments. They also emphasized the importance of feeling and perceiving the room simultaneously over hearing and evaluating a digital sound from headphones or any other amplifiers. For this reason, the study was conducted in real music practice rooms.

5.3. Further Studies

Thirty classical singers contributed to the study. All the vocal types from bass to soprano were present along with a diverse background in vocal studies and age range from 15 to 30 years. However, the numbers of vocal types along with background in vocal studies were not homogeneously distributed. The results might have been influenced and this might be a limitation. The reason was that there are not so many classical singers in Ankara even though there are three major universities with music faculties. Even finding thirty classical singers to participate in the study was quite difficult. Future studies may consider growing the number of respondents in order to strengthen statistical power.

One of the starting points of this study was to test the reliability of the design recommendations indicated in standards for music practice rooms. Along with aforementioned standards in Chapter 2, Wenger Corporation (2008) also published a planning guide for school music facilities. In the related planning guide, it was indicated that untreated music practice rooms should be treated with absorber panels located on the wall surfaces in order to eliminate flutter echoes and undesirable loudness. Nonetheless, the presence of diffuser panels would also create an acoustically balanced environment which would enable clear communication between teachers and students along with communication within an ensemble. The room settings which were designed for this study did not have diffuser panels where necessary. Since the investigation was to primarily test the perceived singing effort and classical singers' RT preferences in the music practice rooms for individual purposes, presence of diffuser panels were considered to be unnecessary. However, considering the classical singers' overall evaluations towards sound quality in room settings, the absence of diffuser panels might have influenced the results.

In Marshall & Meyer's (1985) study, performers preferred parquet floor selection to carpet flooring. Considering the absorption properties of aforementioned materials, it is known that carpet flooring has a tendency to absorb high frequency sound energy unlike parquet flooring. This distinction might be the reason behind practice room preferences. The researchers affirmed the fact and concluded that using carpet on stage floor should not be used. In this study, one of the three room settings had carpet floor. For this reason, the results might be influenced by the floor material selection.

CHAPTER 6

CONCLUSION

Classical singers need to maintain a proper technique with practice to have successful stage performances. In this regard, reverberation time (RT) -the primary acoustical parameter in architectural acoustics- has been studied in music practice rooms, along with the user responses, and an optimum RT is presented. Acoustical design recommendations for music schools include music practice rooms, however, recommended RT values are in a range between 0.6 s and 1.0 s that a 0.4 s difference is considered to be important for such small volumes. Nonetheless, these RT values are not specified for particular instrument groups including the singing voice. As for the research field, there are only few studies focusing on classical singers and music practice rooms. This study, therefore, has investigated the RT preferences of classical singers along with their perceptual responses in music practice rooms. In this context, with the guidance of previous studies, a method has been developed. Eventually, its findings have been evaluated, concluded, and presented to the research field.

The method in this study has combined objective measurements and subjective evaluations. As a first step, three room settings have been designed with RT's of 0.6 s, 0.8 s, and 1.0 s respectively. Potential acoustical problems in small music rooms such as flutter echoes and room resonances have been eliminated or ignored if possible. Then, the actual RT values in room settings were measured using ODEON Room Acoustics Software. In the second step, classical singers' have been asked to sing as high and as low as they can with melisma singing and with different singing volumes in each room setting. A questionnaire was designed and applied to classical singers to obtain answers addressing the research questions.

Primarily, this study has questioned the most preferable RT for classical singers in music practice room (in around 130 m^3 volume) among 0.6 s, 0.8 s, and 1.0 s which are the among the RT values recommended in standards. Data taken from thirty classical singers with different backgrounds in vocal studies including all voice types has shown that for classical singers neither a dead nor a live condition is preferable. Classical singers would like to practice in a condition in which they can hear their voices while slightly exerting an above average singing effort with 0.8 s RT. Therefore, the first hypothesis (given in Chapter 3) has been rejected.

Secondly, perceived singing effort has been questioned regarding its influence on preference. Results have indicated that there is an important connection between perceived singing effort and classical singers' perceptions towards their exerted singing effort. It has been found that as perceived singing effort increases, the room condition becomes absorbent. In contrast, perceived singing effort decreases when RT in a room goes higher. According to classical singers' overall tendency, preference increases where perceived singing effort decreases. Thus, the second hypothesis has not been rejected.

Thirdly, the relationship between perceived singing effort and background in vocal studies has been investigated to understand how education level influences perceived singing effort. Results have indicated that background in vocal studies has no correlation with perceived singing effort. However, further results have shown that experienced classical singers, who have completed their higher education in singing, usually exert less effort than the ones who are currently being trained. Although there is a significant relationship between perceived singing effort and education level of classical singers, third hypothesis has been rejected with these results.

Lastly, the relationship between RT preference and classical singers' background in vocal studies was questioned to understand how education level influenced preferred RT. Results indicated that there is a connection between classical singers' background in vocal studies and preference. As their background in vocal studies increased in duration, their preferences tended towards lower reverberation times. In contrast, preferences tended towards higher reverberation times as background in vocal studies decreased. Accordingly, fourth hypothesis has not been rejected.

Taking overall results into consideration, there are negative relationships between perceived singing effort and education level, and between reverberation time and perceived singing effort. On the other hand, there is a positive relationship between preference of RT and perceived singing effort. As for the most preferred room condition, the responses from classical singers agreed upon the midway condition with 0.8 s RT. Classical singers preferred practicing in a condition that enables them to hear their own voices with only slightly higher singing effort.

As a note for architectural acousticians and even for architects and interior architects/designers, in such music practice rooms with around 130 m^3 volume, reserved for classical singers, the reverberation time criterion can be taken as 0.8 s as this study has shown the preferences of classical singers with a diverse range of background in vocal studies and vocal types.

More research is necessary to determine the acoustical requirements of classical singers in music practice rooms for individual usage. Future studies with similar method designs as this study might consider evaluating classical singers' perceptions within different room volumes. Future studies might also consider an original composition, with lyrics (approximately 5 minutes), arranged for all vocal types as a song being a research instrument in order to conduct a similar preference test. In addition, one should consider asking classical singers to perform the mentioned composition after at least 10 minutes of warm-up exercises. Future studies might also consider investigating the influence of singing with different tempos on preference of room settings. Similarly, different positions of classical singers in a room might be considered to have more extensive findings.

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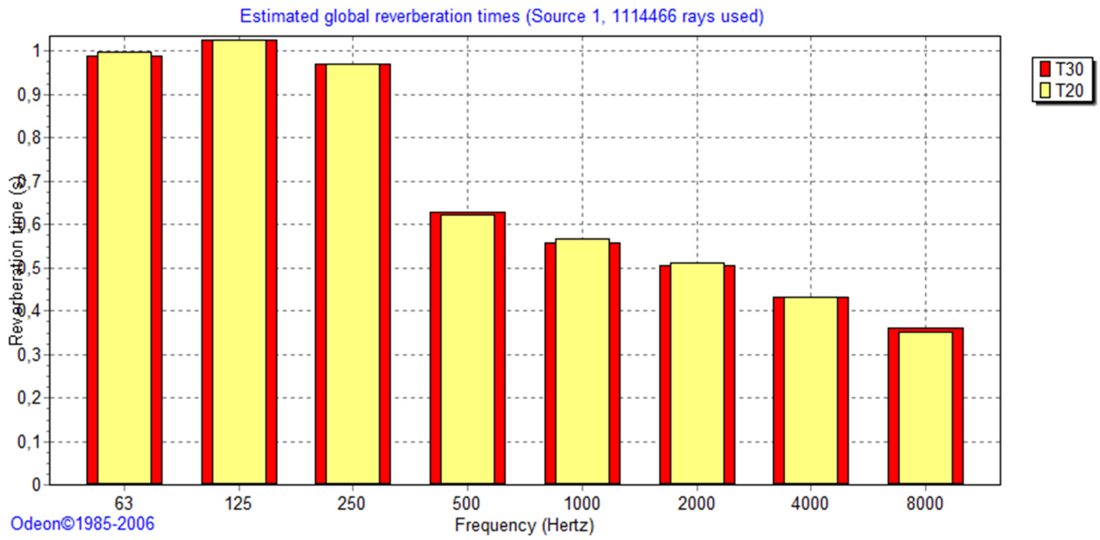
APPENDIX A

ACOUSTICAL MEASUREMENTS



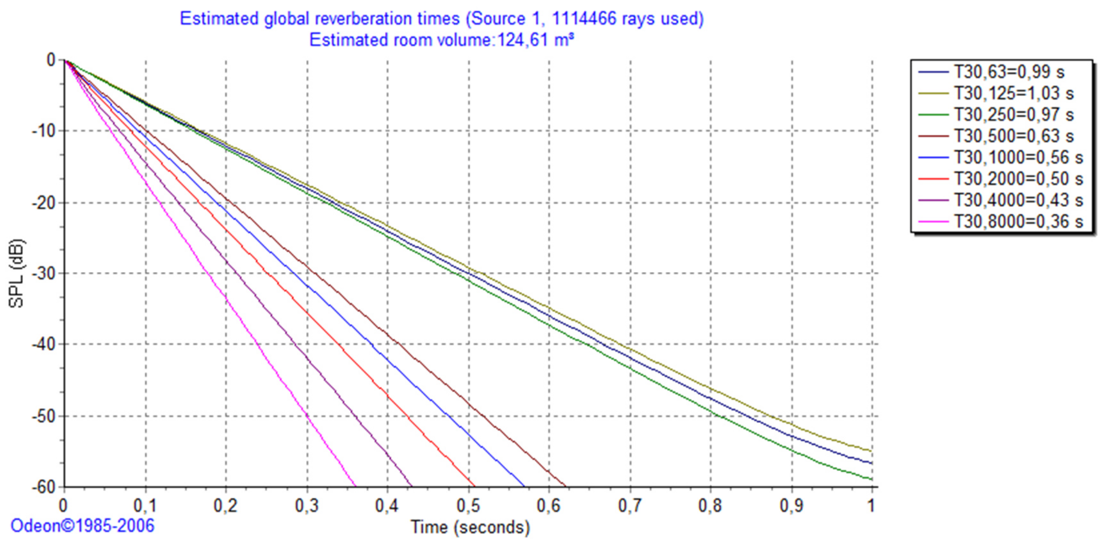
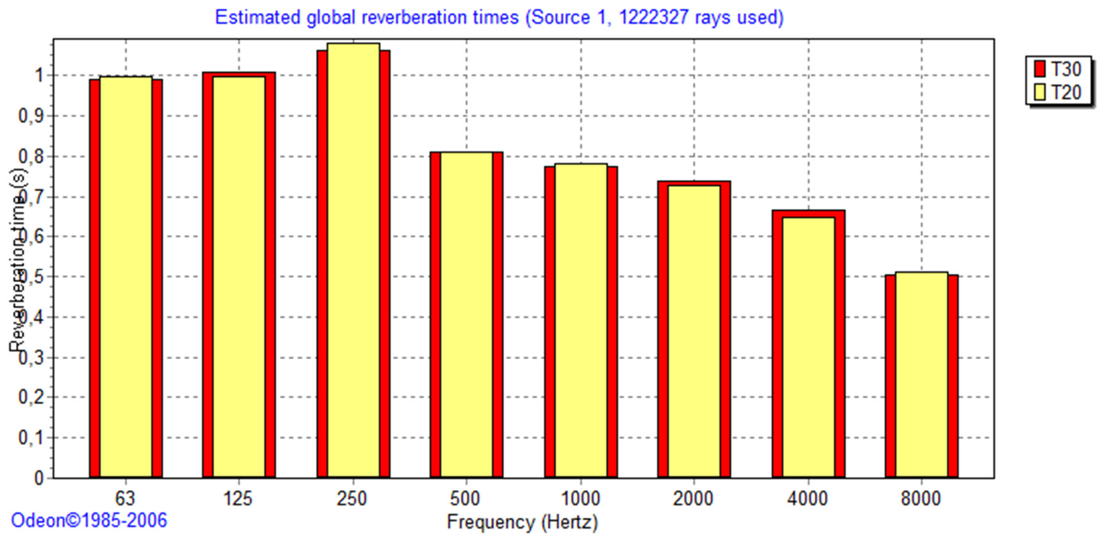


Figure A. 1. Estimated global reverberation times for room setting 1 (T_{20} and T_{30}) via ODEON Room Acoustics Software



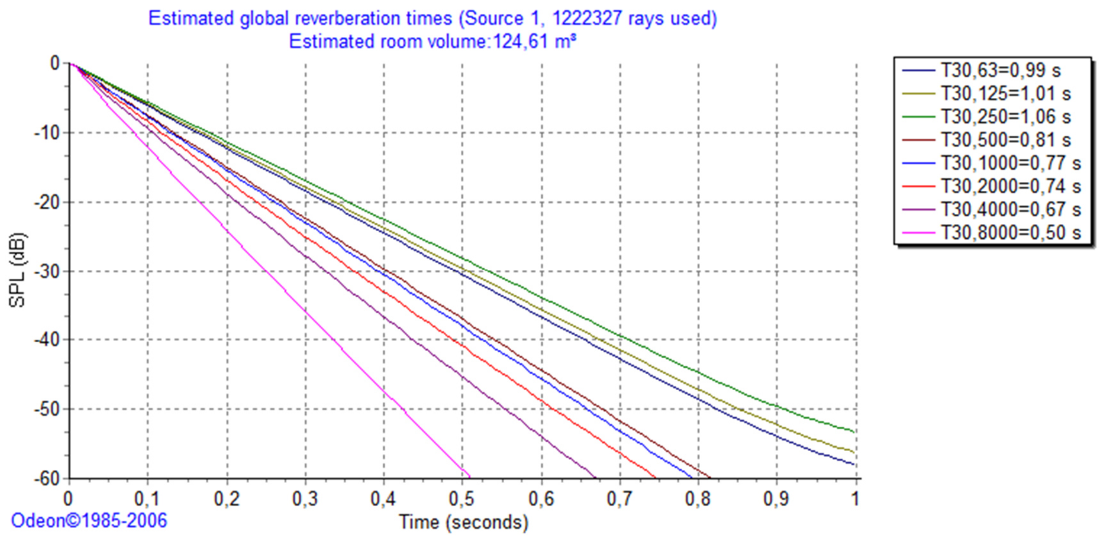
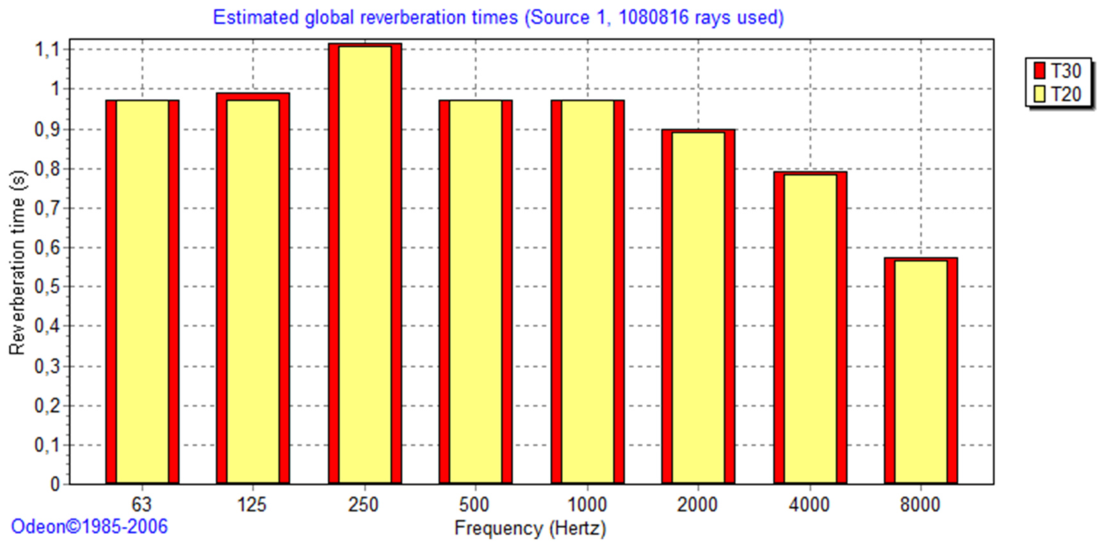


Figure A. 2. Estimated global reverberation times for room setting 2 (T_{20} and T_{30}) via ODEON Room Acoustics Software



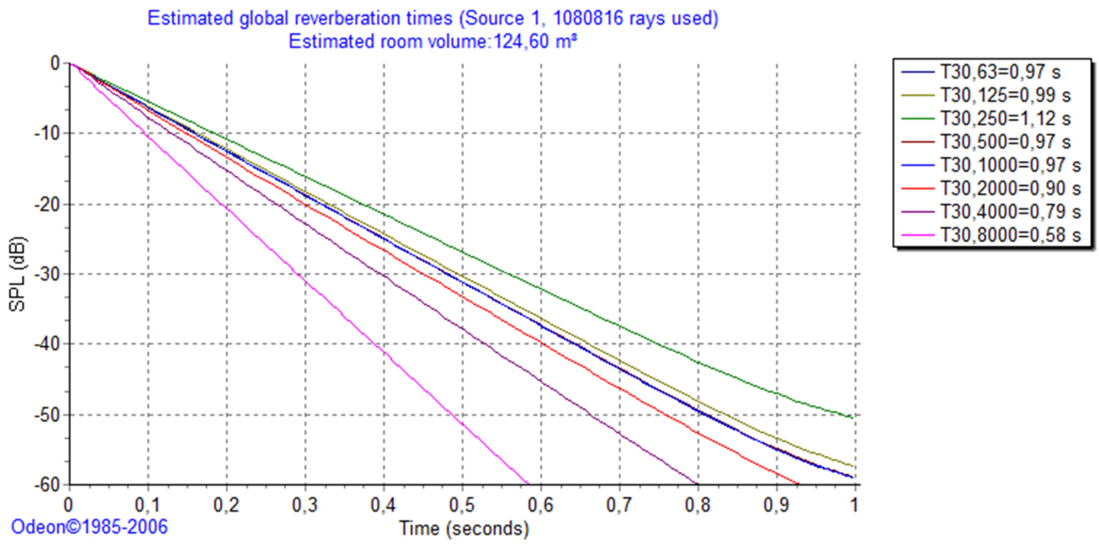


Figure A. 3. Estimated global reverberation times for room setting 3 (T_{20} and T_{30}) via ODEON Room Acoustics Software

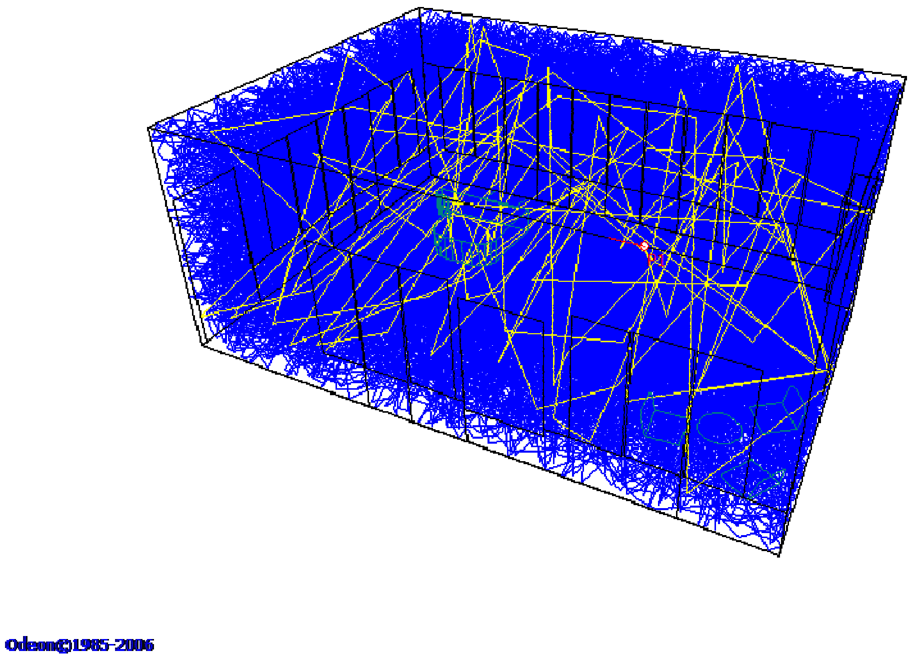


Figure A. 4. Reliability of room model; showing no sound ray leaks out of model

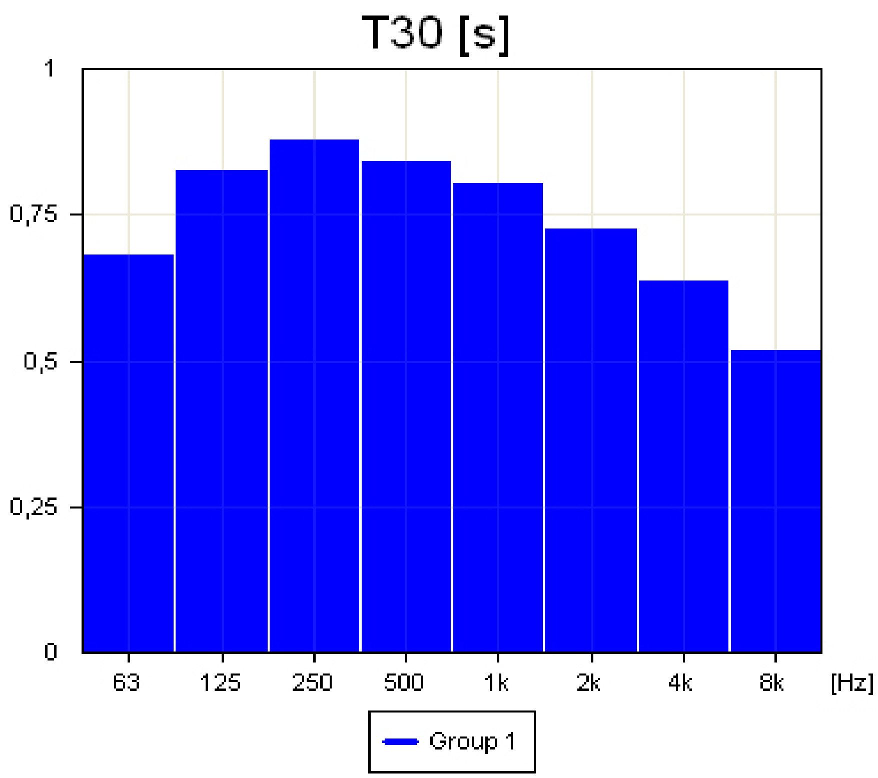


Figure A. 5. Real-size measurement results via DIRAC 3.0 in 1/3 octave band

Frequency [Hz]:	63	125	250	500	1000	2000	4000
EDT [s]:	0,74	0,68	1,12	0,66	0,8	0,75	0,63
T20 [s]:	0,55	0,86	0,9	0,84	0,78	0,74	0,63
T30 [s]:	0,68	0,83	0,88	0,84	0,81	0,73	0,64
Ts [ms]:	49,7	57,3	76,7	52,1	59,8	49,6	39,2
C80 [dB]:	6,46	6,57	3,49	6,87	4,29	5,47	7,59
D50 [-]:	0,75	0,71	0,51	0,61	0,52	0,63	0,73

Figure A. 6. ISO 3382 results given by DIRAC Room Acoustics Software version 3.0

APPENDIX B

DRAWINGS

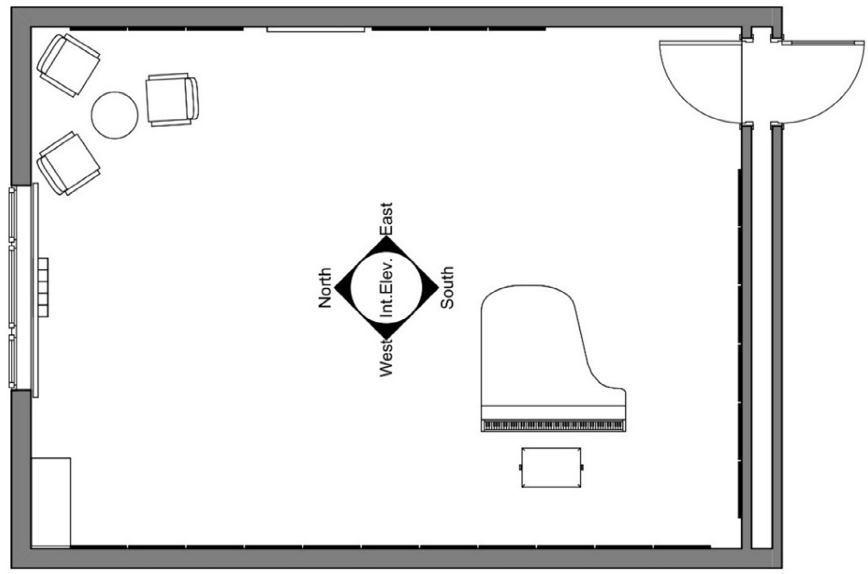


Figure B. 1. Plan drawing of room setting 1 and room setting 2, 1/50 scale

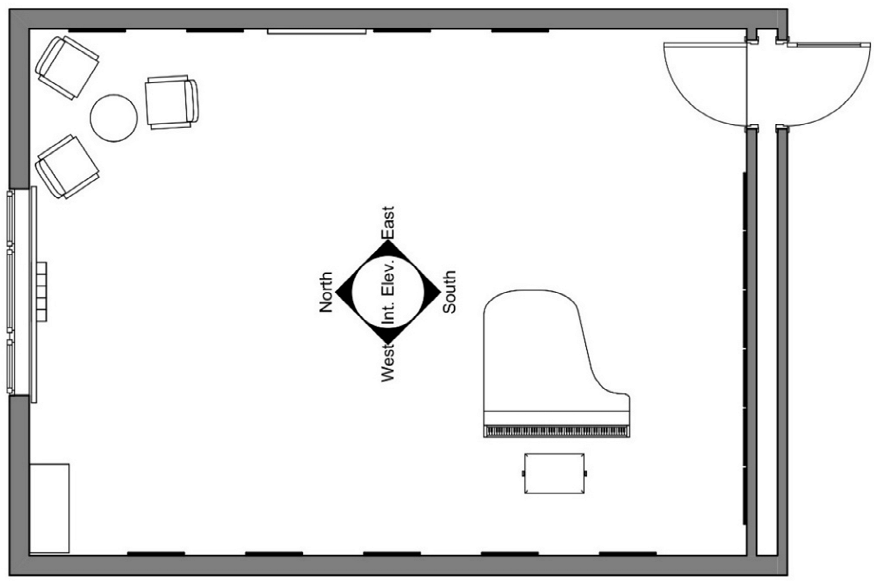


Figure B. 2. Plan drawing of room setting 3, 1/50 scale

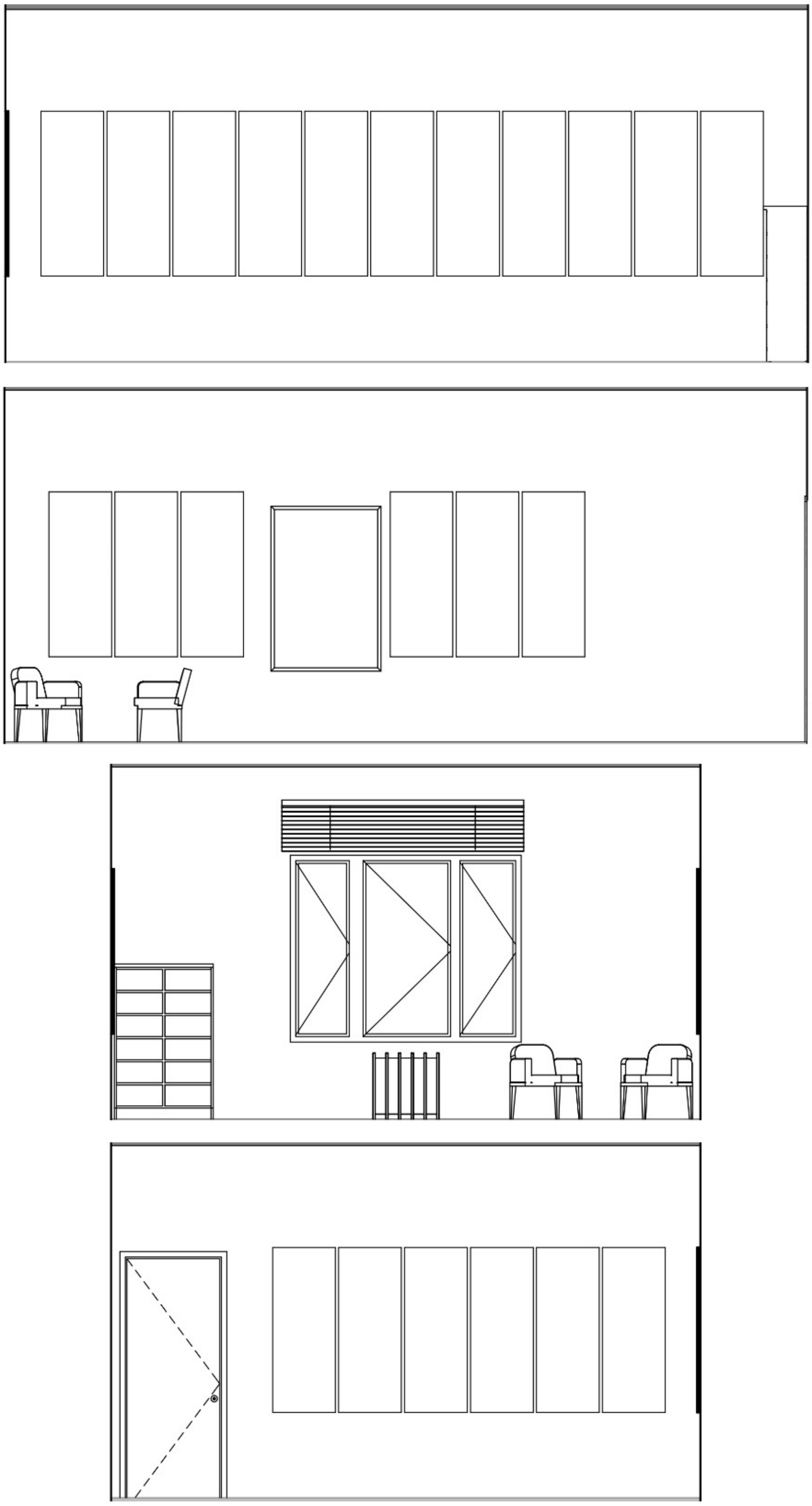


Figure B. 3. Interior elevation drawings of room setting 1 and room setting 2, 1/50 scale

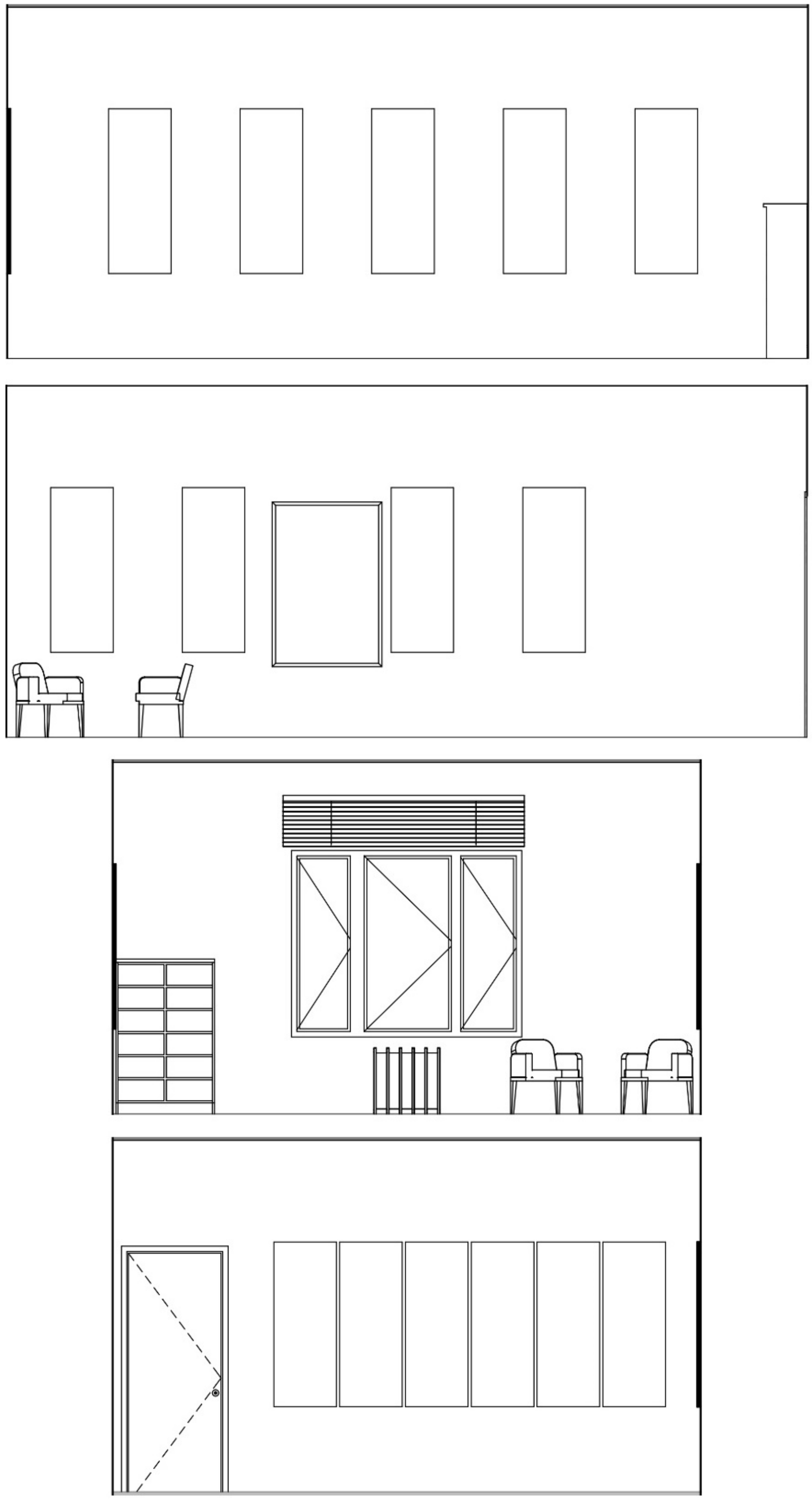


Figure B. 4. Interior elevation drawings of room setting 3, 1/50 scale

APPENDIX C

QUESTIONNAIRE

Bilkent University

Department of Interior Architecture and Environmental Design

Questionnaire to Classical Singing Students in Faculty of Music and Performing Arts, Department of Music

Questionnaire Part 1*

Please tick this box to give your consent to participate in this questionnaire.

Age ☐ less than 15 ☐ 15-19 ☐ 20-24 ☐ 25-29 ☐ More than 30
Gender ☐ Female ☐ Male

Questionnaire Part 2*

Please tick this box to give your consent to participate in this questionnaire.

How many times do you appear in recitals/concerts in a year? ☐ 0 – 2 ☐ 3 – 5 ☐ 6 – 8 ☐ 9 - more
How much time (hours) do you spend in an individual practice room for practicing per week? ☐ 0 – 4 ☐ 5 – 9 ☐ 10 – 14 ☐ 15 – 19 ☐ 20 - more
Have you ever suffered from vocal strain during a daily practice? ☐ Yes ☐ No ☐ No Idea
Do you have a permanent hearing loss? ☐ Yes ☐ No ☐ No Idea
Reverberation in practice rooms affects the performance of classical singers. Do you agree? ☐ Yes ☐ No ☐ No Idea

Figure C. 1. Questionnaire Part 1 and Part 2

Questionnaire Part 3**

This part of the questionnaire formed according to each room setting.

<u>Please answer this part of the questionnaire considering your experience in **"Room Setting 1".**</u>

Please tick this box to give your consent to participate in this questionnaire

How did you perceive your exerted singing effort in this room setting?				
☐ Much more than normal	☐ More t.n.	☐ Normal	☐ Less t.n.	☐ Much less t.n.
How did you perceive the low notes in this room setting?				
☐ Very unclear	☐ Unclear	☐ Neutral	☐ Clear	☐ Very clear
How did you perceive the high notes in this room setting?				
☐ Very unclear	☐ Unclear	☐ Neutral	☐ Clear	☐ Very clear
How did you perceive the pianissimo-paced parts in this room setting?				
☐ Very unclear	☐ Unclear	☐ Neutral	☐ Clear	☐ Very clear
How did you perceive the mezzo-forte-paced parts?				
☐ Very unclear	☐ Unclear	☐ Neutral	☐ Clear	☐ Very clear
How did you perceive the fortissimo-paced parts?				
☐ Very unclear	☐ Unclear	☐ Neutral	☐ Clear	☐ Very clear

t.n. = than normal

Figure C. 2. Questionnaire Part 3 for room setting 1

Questionnaire Part 3**

This part of the questionnaire formed according to each room setting.

<u>Please answer this part of the questionnaire considering your experience in **"Room Setting 2".**</u>

Please tick this box to give your consent to participate in this questionnaire

How did you perceive your exerted singing effort in this room setting?				
☐ Much more than normal	☐ More t.n.	☐ Normal	☐ Less t.n.	☐ Much less t.n.
How did you perceive the low notes in this room setting?				
☐ Very unclear	☐ Unclear	☐ Neutral	☐ Clear	☐ Very clear
How did you perceive the high notes in this room setting?				
☐ Very unclear	☐ Unclear	☐ Neutral	☐ Clear	☐ Very clear
How did you perceive the pianissimo-paced parts in this room setting?				
☐ Very unclear	☐ Unclear	☐ Neutral	☐ Clear	☐ Very clear
How did you perceive the mezzo-forte-paced parts?				
☐ Very unclear	☐ Unclear	☐ Neutral	☐ Clear	☐ Very clear
How did you perceive the fortissimo-paced parts?				
☐ Very unclear	☐ Unclear	☐ Neutral	☐ Clear	☐ Very clear

t.n. = than normal

Figure C. 3. Questionnaire Part 3 for room setting 2

Questionnaire Part 3**

This part of the questionnaire formed according to each room setting.

Please answer this part of the questionnaire considering your experience in **"Room Setting 3".**

Please tick this box to give your consent to participate in this questionnaire

How did you perceive your exerted singing effort in this room setting?				
☐ Much more than normal	☐ More t.n.	☐ Normal	☐ Less t.n.	☐ Much less t.n.
How did you perceive the low notes in this room setting?				
☐ Very unclear	☐ Unclear	☐ Neutral	☐ Clear	☐ Very clear
How did you perceive the high notes in this room setting?				
☐ Very unclear	☐ Unclear	☐ Neutral	☐ Clear	☐ Very clear
How did you perceive the pianissimo-paced parts in this room setting?				
☐ Very unclear	☐ Unclear	☐ Neutral	☐ Clear	☐ Very clear
How did you perceive the mezzo-forte-paced parts?				
☐ Very unclear	☐ Unclear	☐ Neutral	☐ Clear	☐ Very clear
How did you perceive the fortissimo-paced parts?				
☐ Very unclear	☐ Unclear	☐ Neutral	☐ Clear	☐ Very clear

t.n. = than normal

Figure C. 4. Questionnaire Part 3 for room setting 3

Questionnaire Part 4**

Please tick this box to give your consent to participate in this questionnaire

Considering your overall experience, <u>which room setting do you prefer to practice?</u>
☐ Room Setting 1 ☐ Room Setting 2 ☐ Room Setting 3
Additional Comments (Why?):

Notes:

*Questionnaire Part 1 and Part 2 are to be filled before the performances

**Questionnaire Part 3 and Part 4 are to be filled after the performances

Thanks for being a participant.

Figure C. 5. Questionnaire Part 4

APPENDIX D

STATISTICS

Table D. 1. One-way Annova Test, for RT values measured for each room setting

Descriptives

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
RS1	4	,6650	,21016	,10508	,3306	,9994	,50	,97
RS2	4	,8450	,14617	,07309	,6124	1,0776	,74	1,06
RS3	4	,9900	,09274	,04637	,8424	1,1376	,90	1,12
Total	12	,8333	,19874	,05737	,7071	,9596	,50	1,12

Test of Homogeneity of Variances

RT

Levene Statistic	df1	df2	Sig.
1,040	2	9	**,392**

ANOVA

RT

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	,212	2	,106	**4,291**	**,049**
Within Groups	,222	9	,025		
Total	,434	11			

Table D. 2. Kruskal Wallis Test with Tukey Post Hoc Test, for perceived singing effort in each room setting

Kruskal-Wallis Test

Ranks

Room Settings		N	Mean Rank
Perceived Singing Effort	Room Setting 1	30	21,47
	Room Setting 2	30	43,30

	Room Setting 3	30	71,73
	Total	90	

Test Statistics a,b

	Perceived Singing Effort
Chi-Square	59,219
df	2
Asymp. Sig.	**,000**

a. Kruskal Wallis Test

b. Grouping Variable: Room Settings

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Perceived Singing Effort

Tukey HSD

(I) Room Settings		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Room Setting 1	Room Setting 2	-1,133*	,194	,000	-1,60	-,67
	Room Setting 3	-2,467*	,194	,000	-2,93	-2,00
Room Setting 2	Room Setting 1	1,133*	,194	,000	,67	1,60
	Room Setting 3	-1,333*	,194	,000	-1,80	-,87
Room Setting 3	Room Setting 1	2,467*	,194	,000	2,00	2,93
	Room Setting 2	1,333*	,194	,000	,87	1,80

*. The mean difference is significant at the 0.05 level.

Homogeneous Subsets

Perceived Singing Effort

Tukey HSDa

Room Settings	N	Subset for alpha = 0.05		
		1	2	3
Room Setting 1	30	2,27		

Room Setting 2	30		3,40	
Room Setting 3	30			4,73
Sig.		1,000	1,000	1,000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 30,000.

Table D. 3. Kruskal Wallis Test, for perceived low notes in each room setting

Kruskal-Wallis Test

Ranks

Room Settings		N	Mean Rank
Low Notes	Room Setting 1	30	44,27
	Room Setting 2	30	51,30
	Room Setting 3	30	40,93
	Total	90	

Test Statistics[a,b]

	Low Notes
Chi-Square	2,734
df	2
Asymp. Sig.	**,255**

a. Kruskal Wallis Test

b. Grouping Variable: Room Settings

Table D. 4. Kruskal Wallis Test, for perceived high notes in each room setting

Kruskal-Wallis Test

Ranks

Room Settings		N	Mean Rank
High Notes	Room Setting 1	30	43,75
	Room Setting 2	30	50,02
	Room Setting 3	30	42,73
	Total	90	

Test Statistics$_{a,b}$

	High Notes
Chi-Square	1,584
df	2
Asymp. Sig.	**,453**

a. Kruskal Wallis Test

b. Grouping Variable: Room Settings

Table D. 5. Kruskal Wallis Test, for perceived pianissimo-paced parts in each room setting

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum
Pianissimo-paced parts	90	2,92	,851	1	5
Room Settings	90	2,00	,821	1	3

Kruskal-Wallis Test

Ranks

Room Settings		N	Mean Rank
Pianissimo-paced parts	Room Setting 1	30	40,20
	Room Setting 2	30	44,27
	Room Setting 3	30	52,03
	Total	90	

Test Statistics[a,b]

	Pianissimo-paced parts
Chi-Square	3,607
df	2
Asymp. Sig.	**,165**

a. Kruskal Wallis Test

b. Grouping Variable: Room Settings

Table D. 6. Kruskal Wallis Test, for perceived mezzo-forte-paced parts in each room setting

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum
Mezzo-forte-paced parts	90	2,60	,731	1	4
Room Settings	90	2,00	,821	1	3

Kruskal-Wallis Test

Ranks

Room Settings		N	Mean Rank
Mezzo-forte-paced parts	Room Setting 1	30	47,18
	Room Setting 2	30	48,08
	Room Setting 3	30	41,23
	Total	90	

Test Statistics[a,b]

	Mezzo-forte-paced parts
Chi-Square	1,447
df	2
Asymp. Sig.	**,485**

a. Kruskal Wallis Test

b. Grouping Variable: Room Settings

Table D. 7. Kruskal Wallis Test, for perceived fortissimo-paced parts in each room setting

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum
Fortissimo-paced parts	90	2,92	,722	2	5
Room Settings	90	2,00	,821	1	3

Kruskal-Wallis Test

Ranks

Room Settings		N	Mean Rank
Fortissimo-paced parts	Room Setting 1	30	45,00
	Room Setting 2	30	49,80
	Room Setting 3	30	41,70
	Total	90	

Test Statistics[a,b]

	Fortissimo-paced parts
Chi-Square	1,745
df	2
Asymp. Sig.	**,418**

a. Kruskal Wallis Test

b. Grouping Variable: Room Settings

Table D. 8. Relationship between preferred room setting and perceived singing effort

Descriptive Statistics

	Mean	Std. Deviation	N
Preferred room setting	1,93	,691	30
Perceived exerted singing effort in preferred room setting	3,37	1,033	30

Correlations

		Preferred room setting	Perceived exerted singing effort in preferred room setting
Preferred room setting	Pearson Correlation	1	**,614****
	Sig. (2-tailed)		**,000**
	N	30	30
Perceived exerted singing effort in preferred room setting	Pearson Correlation	**,614****	1
	Sig. (2-tailed)	**,000**	
	N	30	30

**. Correlation is significant at the 0.01 level (2-tailed).

Table D. 9. Relationship between preferred room setting and background in vocal studies

Descriptive Statistics			
	Mean	Std. Deviation	N
Background in vocal studies	3,10	1,494	30
Preferred room setting	1,93	,691	30

Correlations			
	Background in vocal studies		Preferred room setting
Background in vocal studies	Pearson Correlation	1	**-,594****
	Sig. (2-tailed)		**,001**
The most preferred room setting	Pearson Correlation	**-,594****	1
	Sig. (2-tailed)	**,001**	
	N	30	30

Table D. 10. Relationship between perceived singing effort and background in vocal studies

Correlations				
			Perceived exerted singing effort	Background in vocal studies
Spearman's rho	Perceived exerted singing effort	Correlation Coefficient	1,000	**-,162**
		Sig. (2-tailed)		**,392**
		N	30	30
	Background in vocal studies	Correlation Coefficient	**-,162**	1,000
		Sig. (2-tailed)	**,392**	
		N	30	30

Table D. 11. Relationship between perceived singing effort and background in vocal studies as unexperienced and experienced classical singers

Preference of room setting*Background in vocal studies as unexperienced and experienced classical singers **Crosstabulation** Count				
		Background in vocal studies as unexperienced and experienced classical singers		Total
		1	2	
Preferred room setting	Room Setting 1	2	6	8
	Room Setting 2	10	6	16
	Room Setting 3	6	0	6
Total		18	12	30

Symmetric Measures

		Value	Approx. Sig.
Nominal by Nominal	Phi	**,520**	**,017**
	Cramer's V	**,520**	**,017**
N of Valid Cases		30	